

# THE AMERICAN MINERALOGIST

JOURNAL OF THE MINERALOGICAL SOCIETY OF AMERICA

Vol. 18

JULY, 1933

No. 7

## EMPLECTITE AND THE ZINKENITE GROUP

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### SUMMARY

Two-circle measurements of seven crystals of emplectite ( $\text{Cu}_2\text{S} \cdot \text{Bi}_2\text{S}_3$ ) from Johanngeorgenstadt, Saxony, gave 26 forms of which 21 are new. Setting the striated zone vertical and the cleavage parallel to  $a(100)$  the crystals are orthorhombic with the elements:  $p_0=0.8093$ ;  $q_0=0.6389$ .  $a:b:c=0.7894:1:0.6389$ .

The published orientations and unsatisfactory elements of emplectite are critically examined. The new data on emplectite strengthen the accepted isomorphism with chalcostibite. Suitably reorientated, zinkenite also shows good correspondence as far as the meagre data on this mineral go.

### EMPLECTITE

A critical study of the isomorphous relations supposed to exist among the members of the Zinkenite Group of Dana<sup>1</sup> led to a search in the Harvard Mineral Collection for measurable material which might throw further light on these imperfectly known minerals. The search was unsuccessful except in the case of emplectite (*Kupferwismuthglanz*), of which we were fortunate in finding a number of richly developed crystals enabling us to correct and extend considerably the scanty crystallographic data of this species. The improved knowledge of emplectite also suggested a revised presentation of the crystallography of the zinkenite group.

The measurable crystals of emplectite were detached from a specimen from Johanngeorgenstadt in Saxony, a locality from which measurements have not been previously reported. The emplectite, in some cases partly filmed with limonite, is associated with quartz and chalcopyrite. The crystals are striated prisms with an average thickness of about half a millimeter. The shape of the cross-section is in some cases a fairly regular, but strongly rounded, orthorhombic prism. In some cases the cross-section is flattened parallel to the perfect cleavage which is pinacoidal and lies in the

<sup>1</sup> *System*, 6th ed., 1892. Goldschmidt discusses the spelling of zinkenite (zinckenite) at some length (*Index*, III, 332, 1891) and recommends the latter form. Both spellings have been used from the first; we prefer the simpler form adopted by Dana.

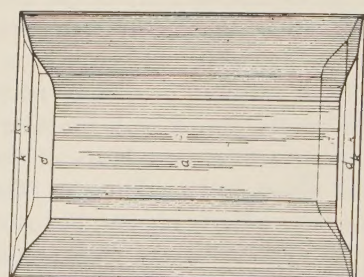
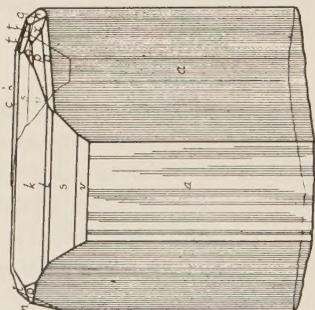
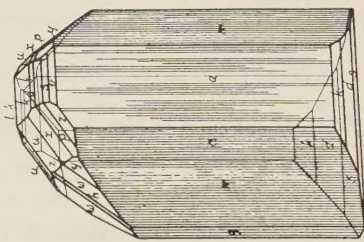
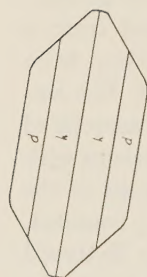
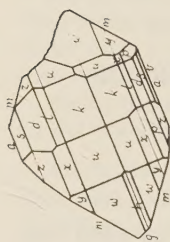


FIG. 1

FIG. 2

FIG. 3

FIG. 1. EMPLECTITE. Typical simple crystal ( $1.0 \times 0.45$  mm.) showing the curved striated prism zone, the front pinacoid (cleavage) and the two dominant macrodomes. Forms:  $a(100)$ ,  $k(103)$ ,  $d(101)$ .

FIG. 2. EMPLECTITE. Crystal of common type ( $0.4 \times 0.25$  mm.) with large macrodomes and small brachydomes and pyramids. Forms:  $c(001)$ ,  $a(100)$ ,  $h(021)$ ,  $n(061)$ ,  $k(103)$ ,  $l(203)$ ,  $s(503)$ ,  $v(703)$ ,  $o(112)$ ,  $q(332)$ ,  $t(136)$ ,  $x(233)$ .

FIG. 3. EMPLECTITE. Doubly terminated crystal with unusually well developed pyramidal forms ( $0.5 \times 0.3$  mm.) Forms:  $a(100)$ ,  $m(110)$ ,  $g(130)$ ,  $h(021)$ ,  $k(103)$ ,  $d(101)$ ,  $s(503)$ ,  $v(703)$ ,  $p(111)$ ,  $u(133)$ ,  $w(163)$ ,  $x(233)$ ,  $y(263)$ ,  $z(433)$ . The hemimorphic appearance is deceptive; the lower termination has minute pyramidal faces like those in fig. 2.



striated zone; in others the flattening follows a pair of dominant parallel prism faces. Irregular cross-sections due to alternations of the prism and cleavage pinacoid are also represented.

The striated prisms are terminated, under favorable conditions at both ends, by large and brilliant faces of domatic aspect which evidently form a vertical zone with the plane of cleavage (fig. 1). Closer examination reveals the presence of numerous pyramidal faces which are for the most part exceedingly small. In some cases the pyramids are better developed and arranged in discernable radial zones (fig. 2) or in zones parallel to the dominant dome zone (fig. 3).

On the two-circle goniometer the striated zone gives trains of weak and valueless reflections with a few good single images or bright bundles of nearly coincident signals. The plane of the cleavage almost invariably gives a strong reflection; the other pinacoid in the striated zone is, on the other hand, rarely seen as a true face. The best prism signals were recorded and found to lie in simple positions; but it would have been impossible to choose a satisfactory unit form in the striated zone without reference to the terminations. This is also true, as we found by trial, of unterminated needles of emplectite from the Tannebaum-Stolln mine, Swartzenberg, Saxony, the source of the material on which the original measurements were made.

The terminal faces are brilliant, smooth planes giving good single images which vary in brightness according to the size of the face. The signals from the larger faces leave nothing to be desired, and even the reflections from the smallest faces fall into positions which vary within tolerably narrow limits.

The observations on seven selected crystals are summarized in the following table. From the weighted averages of all the good observations we determined the symmetry and elements of emplectite as follows:

EMPLECTITE: orthorhombic, holohedral

$$\begin{aligned}p_0 &= 0.8093 \\q_0 &= 0.6389 \\a:b:c &= 0.7894:1:0.6389\end{aligned}$$

From these elements we obtained the calculated angles in the following table which agree satisfactorily with the observations.

TABLE I. EMPLECTITE: TWO-CIRCLE ANGLE-TABLE.

Form	Calculated		Observed av.		Observed limits		No. of faces	No. of crystals	Av. quality of signal
	$\phi$	$\rho$	$\phi$	$\rho$	$\phi$	$\rho$			
<i>c</i> 001	0°00'	0°00'	0°09'	0°00'	..	..	5	5	fair
<i>b</i> 010	90 00	90 00	89 54	90 00	89°48'-90°09'	..	1	1	fair
<i>a</i> 100	"	"	"	"	..	..	9	6	poor
<i>g</i> 130	22 53½	"	23 01	"	22 58 -23 04	..	2	2	poor
<i>i</i> 230	40 11	"	39 52	"	..	..	1	1	fair
<i>r</i> 560	46 33	"	46 10	"	46 00 -46 20	..	..	..	..
<i>m</i> 110	51 42½	"	51 49½	"	51 39 -52 00	..	2	1	poor
<i>j</i> 430	59 22	"	59 00	"	..	..	1	1	excellent
<i>h</i> 021	0 00	51 57	0 02	51 53	-0 12 - 0 13	51°45'-52°08'	9	4	fair
<i>n</i> 061	"	75 22½	"	75 32	"	75 15 -76 07	4	4	fair
<i>k</i> 103	90 00	15 06	89 54	15 06	89 48 -90 09	14 53 -15 43	7	7	excellent
<i>l</i> 203	"	28 21	"	28 23	"	28 04 -28 40	7	7	poor
<i>d</i> 101	"	38 59	"	38 59½	"	38 49 -39 08	5	5	excellent
<i>e</i> 403	"	47 10½	"	47 25½	"	46 54 -48 10	2	2	poor
<i>s</i> 503	"	53 27	"	53 36	"	53 18 -54 09	7	7	fair
<i>f</i> 201	"	58 17½	"	58 48	"	58 48 -58 48½	2	2	poor
<i>v</i> 703	"	62 05½	"	62 37	"	61 10 -63 27	6	6	poor
<i>o</i> 112	51 42½	27 16½	51 39	27 18½	51 12 -52 18	27 12 -27 32	8	5	poor
<i>p</i> 111	"	45 52½	51 40	45 54½	"	45 48 -46 10	4	4	fair
<i>q</i> 332	"	57 07	51 37	57 10	51 12 -51 58	57 00 -57 21	2	2	poor
<i>t</i> 136	22 53½	19 07½	23 06	18 36	22 57 -23 44	18 30 -18 53	4	2	poor
<i>u</i> 133	"	34 44½	22 54	34 38½	22 39 -23 12	34 20 -34 50	11	4	good
<i>w</i> 163	11 55½	52 33½	11 57½	52 30	11 44 -12 09	52 20 -52 38	8	3	good
<i>x</i> 233	40 11	39 54	40 08	40 01½	39 52 -40 40	39 45 -40 17	11	6	good
<i>y</i> 263	22 53½	54 12½	22 56	54 09	22 44 -23 06	54 00 -54 19	12	5	good
<i>z</i> 433	59 22	51 25½	59 22	51 22½	59 11 -59 36	51 03 -51 35	5	2	fair

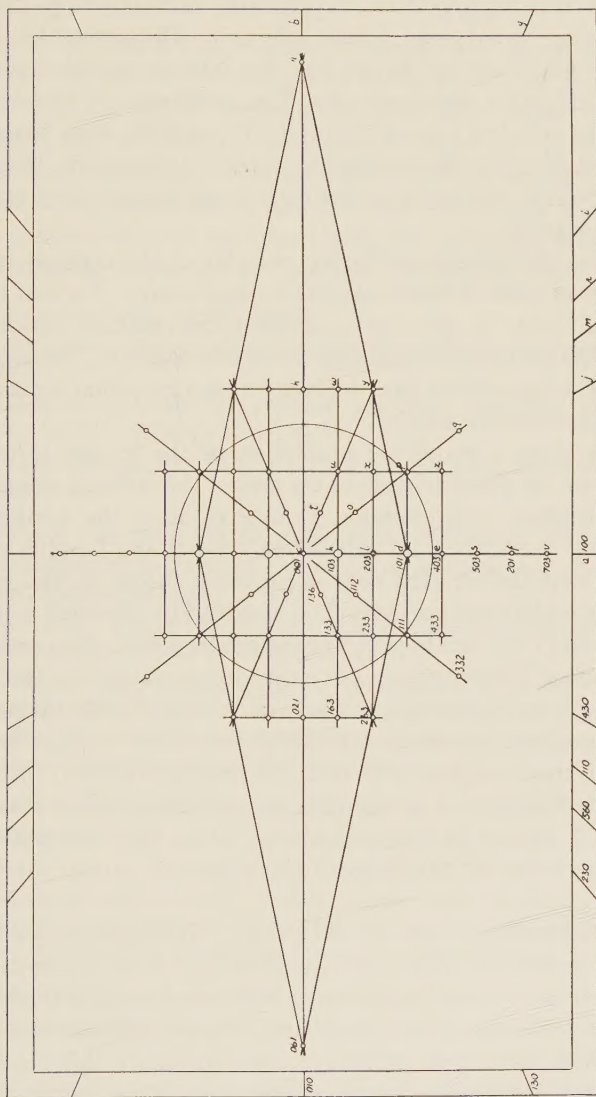


FIG. 4. EMPLECTITE. Gnomonic projection of the known forms on the plane normal to the axis of the striated zone. The dominant terminal forms,  $k(103)$ ,  $d(101)$ , are shown in larger points.



Of the forms given,  $a(100)$ ,  $m(110) = g(110)$  of Dauber,<sup>2</sup>  $r(560) = z(110)$  of Weisbach,<sup>3</sup>  $k(103)$ ,  $d(101)$  have been observed before; the remaining twenty-one forms are new. The prismatic form  $r(560)$  was not observed by us but the form is included on the basis of Weisbach's measurements. The remainder of Weisbach's forms in the striated zone,  $x(170)$ ,  $y(120)$ ,  $u(320)$ , were based on single unsatisfactory measurements; since, furthermore, the true symbols of these forms are exceedingly complicated, they are rejected as uncertain.

In view of the general similarity of habit of the crystals measured, a special table of combinations is unnecessary. The last three columns of Table I give the equivalent information. Since the quality of the terminal faces is approximately constant, the average quality of the signal from each form gives an approximate measure of its average relative size.

Figure 4 gives a gnomonic projection of the known forms of emplectite on the plane normal to the axis of the striated zone. The diagram displays orthorhombic symmetry and the projection points group themselves in well defined radial and parallel zones indicating that the striated zone is properly chosen as the prism zone. The simplest symbols would be obtained by choosing  $y$  as the unit pyramid (111); but to preserve the analogy with chalcostibite, to be discussed presently, we have decided to take  $p$  as the unit with  $a$ , the plane of cleavage, as the front pinacoid (100). Although the list of symbols obtained with this choice of unit is slightly less simple than that based on  $y$  as unit, the position and unit form we have adopted leads to  $d$  as the unit macrodome (101), a stronger form than  $l$ , and  $m$  as the unit prism (110), the form which is mainly responsible for the shape of the prismatic part of the crystals.

PREVIOUS ORIENTATIONS AND ELEMENTS. The elements we have given for emplectite differ very considerably from those in the works of reference when transformed into corresponding positions. This is due to the fact that Weisbach,<sup>4</sup> whose measurements are the last which have been published, observed only the cleavage-pinacoid, two forms in the macrodome zone and a number of poorly developed faces in the unsatisfactory striated zone. Weisbach thus

<sup>2</sup> *Pogg. Ann.*, 92, 241, 1854.

<sup>3</sup> *Pogg. Ann.*, 128, 435, 1866.

<sup>4</sup> *Pogg. Ann.*, 128, 435, 1866.

obtained a good value for the element  $p_0(=c/a)$ ; but due to an unhappy choice of unit prism,  $z(110)$ Weisbach =  $r(560)$  of this paper, Weisbach's  $q_0(=c)$  has a complicated relation to the value of this element as determined by the new terminal forms. To bring out correspondence between sartorite and emplectite Groth<sup>5</sup> assumed that Weisbach's  $z(110)$  should have the symbol (650). The resulting elements, which have no practical relation to emplectite, were transformed into a new position and widely adopted. It will be of some value to examine briefly the published orientations and elements of emplectite and see how they were obtained.

Dauber, *Pogg. Ann.*, **92**, 241, 1854.

*Orientation*: Like ours; axis of the striated zone is the  $c$ -axis; cleavage parallel to  $a(100)$ .

*Elements*:  $a:b:c=0.8000:1:0.6520$ ; calculated from the observed angles:  $a(100)\wedge d(101)=50^\circ49'$ ;  $a(100)\wedge g(110)=38^\circ39\frac{1}{2}'$ .

These elements, derived from the first measurements made on emplectite, are similar to ours.

Weisbach, *Pogg. Ann.*, **128**, 435, 1866; Victor Goldschmidt, *Winkeltabellen*, **1897**.

*Orientation*: Like Dauber's and ours; axis of the striated zone is the  $c$ -axis; cleavage parallel to  $a(100)$ .

*Elements*:  $a:b:c=0.9601:1:0.7738$ ; calculated from the observed angles:  $a(100)\wedge d(101)=51^\circ08'$ ;  $a(100)\wedge z(110)=43^\circ50'$ .

Weisbach failed to find Dauber's  $g(110)$  and took  $z(110)$ , which corresponds to our  $r(560)$ , as unit prism. With  $z(560)$  Weisbach's observations lead to elements which are close to ours:  $a:b:c=0.8001:1:0.6448$  (Weisbach). All subsequent presentations of emplectite rest on Weisbach's observations.

Groth, *Tabellarische Übersicht*, 2nd ed., **1882**; 3rd ed., **1889**.

*Orientation*: The axis of the striated zone is the  $b$ -axis; cleavage parallel to  $c(001)$ .

*Elements*:  $a:b:c=0.5385:1:0.6204$ ; obtained from Weisbach's measurements, giving the symbol (650) to Weisbach's  $z(110)$ , and then interchanging the axes so that  $a$  (Groth) =  $1/2c$  (Weisbach),  $c$  (Groth) =  $a/2c$  (Weisbach).

Victor Goldschmidt, *Index*, **1886**.

*Orientation*: The axis of the striated zone is the  $a$ -axis; cleavage parallel to  $c(001)$ .

*Elements*:  $a:b:c=0.7738:1:0.9601$ , obtained by interchanging the  $a$ - and  $c$ -axes of Weisbach.

Goldschmidt rejects Groth's artificial symbol (650) for Weisbach's form  $z$  in favour of the original symbol (110).

<sup>5</sup> *Tabellarische Übersicht*, 2nd ed., **1882**.

Dana, *System*, 6th ed., 1892. Groth, *Tabellarische Übersicht*, 4th ed., 1898. Spencer, *Min. Mag.*, 11, 191, 1897. Buttgenbach, *Tableaux*, 1918. Groth, *Tabellen*, 1921. Doelter, *Handbuch*, 1925.

*Orientation*: Like that of Groth, 1882; the axis of the striated zone is the *b*-axis; cleavage parallel to *c*(001).

*Elements*:  $a:b:c=0.5430:1:0.6256$ , obtained from Weisbach's measurements exactly as were those of Groth, using the artificial symbol (650) for the form *z*, but employing the measured angle  $a(100)\wedge k(103)=75^{\circ}05'$  instead of  $a(100)\wedge d(101)=51^{\circ}08'$ .

Hintze, *Handbuch*, 1902.

*Orientation*: Like that of Groth (1882); Dana (1892); the axis of the striated zone is the *b*-axis; cleavage parallel to *c*(001).

*Elements*:  $a:b:c=0.6517:1:0.6256$ , calculated from Weisbach's observed angles,  $a(100)\wedge k(103)=75^{\circ}05'$ ;  $a(100)\wedge z(110)=43^{\circ}50'$ , and transformed exactly as stated under Groth (1882). Hintze's elements thus correspond exactly with those of Groth (1882) with the original symbol (110) restored to the form *z*.

Hofmann, *Z. Krist.*, 84, 177, 1933.

*Orientation*: Like that of Hintze (1902).

*Elements*:  $a:b:c=1.573:1:3.729$ , obtained from a determination of the dimensions of the unit cell. Transforming our elements into Hofmann's position and trebling the *c*-axis, we obtain:  $a:b:c=1.5652:1:3.7068$ . Although the trebled *c*-axis in this position is an acceptable choice for emplectite, we prefer to conform to the orientation and elements established for chalcostibite in Ernst's elaborate study (*N. Jahrb. f. Min.*, Beil. LVI A, 275, 1927).

#### THE ZINKENITE GROUP

Dana's zinkenite group comprises minerals with the general formula,  $RS(As, Sb, Bi)_2S_3$ . The crystallographically known members of the group are:

Zinkenite.....	PbS · Sb <sub>2</sub> S <sub>3</sub>
Sartorite (scleroclase).....	PbS · As <sub>2</sub> S <sub>3</sub>
Emplectite.....	Cu <sub>2</sub> S · Bi <sub>2</sub> S <sub>3</sub>
Chalcostibite (wolfsbergite, guejarite).....	Cu <sub>2</sub> S · Sb <sub>2</sub> S <sub>3</sub>

These four minerals have been presented as an isomorphous orthorhombic group by Groth,<sup>6</sup> Goldschmidt<sup>7</sup> and Dana,<sup>8</sup> each using a different orientation. Later Goldschmidt<sup>9</sup> abandoned the isomorphous grouping in the interest of simple symbols, and more recently Groth<sup>10</sup> divided the group placing zinkenite (orthorhom-

<sup>6</sup> *Tabellarische Übersicht*, 2nd ed., 24, 1882.

<sup>7</sup> *Index*, I, 548, 1886.

<sup>8</sup> *System*, 6th ed., 111, 1892.

<sup>9</sup> *Winkeltabellen*, 1897.

<sup>10</sup> *Mineralogische Tabellen*, 1921.



bic, possibly monoclinic) with sartorite (monoclinic), retaining emplectite and chalcostibite as an isomorphous pair. A detailed study of sartorite by Smith and Solly<sup>11</sup> showed that this mineral is monoclinic with a form system even stranger than that of calaverite. Sartorite thus falls definitely out of the orthorhombic group.

The scanty crystallographic data on zinkenite rest on early measurements by Rose<sup>12</sup> supplemented by approximate measurements by Spencer<sup>13</sup> on material referred without complete certainty to zinkenite. Zinkenite occurs in striated and channeled orthorhombic prisms of hexagonal appearance due apparently to repeated twinning on a plane in the striated zone. Single crystals are rare and the known forms are the three pinacoids which are usually feebly developed, a dome  $k$  inclined to the axis of the striated zone at  $14^{\circ}42'$  and a prismatic form  $\epsilon$  inclined at  $29^{\circ}40\frac{1}{2}'$  to the pinacoid which lies in zone with the dome. There is no cleavage.

Correspondence between zinkenite and emplectite is obtained in two positions:

1. Making the axis of the striated zone of zinkenite the  $b$ -axis and placing the form  $k$  in brachydome position, we have:

ZINKENITE	EMPLECTITE
$k(061)$ ; $\rho = 75^{\circ}18'$	$n(061)$ ; $\rho = 75^{\circ}22'$
$\epsilon(203)$ ; $\rho = 29\ 40\frac{1}{2}$	$l(203)$ ; $\rho = 28\ 21$

2. Setting the axis of the striated zone vertical and the dome  $k$  in macrodome position:

ZINKENITE	EMPLECTITE
$k(103)$ ; $\rho = 14^{\circ}42'$	$k(103)$ ; $\rho = 15^{\circ}06'$
$\epsilon(430)$ ; $\rho = 60\ 19\frac{1}{2}$	$j(430)$ ; $\rho = 59\ 22$

In the absence of cleavage in zinkenite we have adopted the second and simpler alternative, thereby bringing the striated zone into the same position as in emplectite.

In a detailed study of chalcostibite Ernst<sup>14</sup> has retained the orientation and elements of Goldschmidt.<sup>15</sup> In this position the striated zone is set vertical and the cleavage plane is made the front pinacoid, which is the position we have adopted for emplectite.

<sup>11</sup> *Min. Mag.*, **18**, 259, 1919.

<sup>12</sup> *Pogg. Ann.*, **7**, 91, 1826.

<sup>13</sup> *Min. Mag.*, **11**, 188, 1897.

<sup>14</sup> *N. Jb. Min., Beil.* **56**, A, 275, 1927.

<sup>15</sup> *Winkeltabellen*, 1897.

TABLE II. THE ZINKENITE GROUP.

	ZINKENITE	EMPLECTITE	CHALCOSTIBITE
Composition.....	$\text{PbS} \cdot \text{Sb}_2\text{S}_3$	$\text{Cu}_2\text{S} \cdot \text{Bi}_2\text{S}_3$	$\text{Cu}_2\text{S} \cdot \text{Sb}_2\text{S}_3$
Habit.....	Striated prismatic zone. Dominant macrodomes.	Striated prismatic zone. Dominant macrodomes.	Striated prismatic zone. Dominant macrodomes.
Orientation.....	Striated zone vertical. No cleav.	Striated zone vertical. Cleav. (100)	Striated zone vertical. Cleav. (100)
Elements.....	$p_0=0.7870$ $q_0=0.5980$ $a=0.7598$ $c=0.5980$	$p_0=0.8093$ $q_0=0.6389$ $a=0.7894$ $c=0.6389$	$p_0=0.7818$ $q_0=0.6275$ $a=0.8026$ $c=0.6275$
Angles, (001) $\wedge$ (103)	$14^\circ 42'$	$15^\circ 06'$	$14^\circ 36\frac{1}{2}'$
(001) $\wedge$ (101)	(38 12)	38 59	38 01
(001) $\wedge$ (111)	(44 40)	$45\ 52\frac{1}{2}$	$45\ 04\frac{1}{2}$
(010) $\wedge$ (110)	(52 46)	$51\ 42\frac{1}{2}$	51 15
Forms in common			
(001)	<i>b</i>	<i>c</i>	<i>b</i>
(010)	<i>a</i>	<i>b</i>	<i>a</i>
(100)	<i>c</i>	<i>a</i>	<i>c</i>
(430)	$\epsilon$	<i>j</i>	<i>j</i>
(110)	.	<i>m</i>	<i>h</i>
(230)	.	<i>i</i>	<i>d</i>
(130)	.	<i>g</i>	<i>g</i>
(103)	<i>k</i>	<i>k</i>	<i>u</i>
(101)	.	<i>d</i>	<i>t</i>
(503)	.	<i>s</i>	<i>s</i>
(201)	.	<i>f</i>	<i>f</i>
(111)	.	<i>p</i>	<i>p</i>
(133)	.	<i>u</i>	$\tau$
(233)	.	<i>x</i>	<i>X</i>
(433)	.	<i>z</i>	$\psi$

Table II and fig. 5 exhibit the correspondence between the crystallographically known orthorhombic members of the zinkenite group. As was rightly surmised but unhappily stated in the past, emplectite and chalcostibite form an isomorphous pair. The new data now show that the correspondence appears not only in

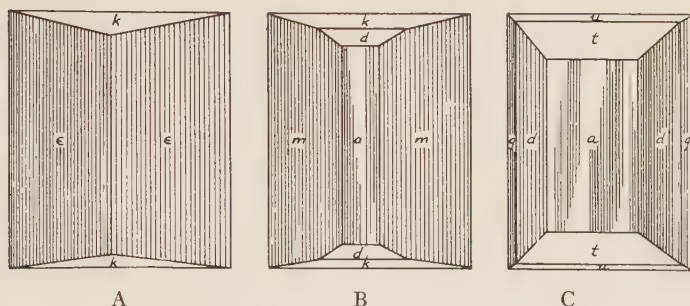


FIG. 5. ZINKENITE GROUP. Simple crystals in corresponding positions.

A. ZINKENITE with  $\epsilon(430)$ ,  $k(103)$ ; after Rose (1826) in Victor Goldschmidt, *Atlas*, IX, Plate 65, fig. 2, 1923.

B. Emplectite with  $a(100)$  cleavage,  $m(110)$ ,  $k(103)$ ,  $d(101)$ .

C. Chalcostibite (wolfsbergite) with  $a(100)$  cleavage,  $g(130)$ ,  $d(230)$ ,  $u(103)$ ,  $t(101)$ . Simplified after Ernst, *N. Jb. Min.*, Beil. 56 A, fig. 1, 283, 1927.

the composition, habit, orientation with respect to cleavage, elements and angles, but also in a list of 15 forms in common. As far as the data go zinkenite also corresponds well with emplectite and chalcostibite, but the agreement should be regarded as provisional. Although zinkenite gives its name to the group, it is now the most imperfectly known member.



# X-RAY STUDY OF PYRITE OR MARCASITE CONCRETIONS IN THE ROCKS OF THE CLEVELAND, OHIO, QUADRANGLES

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## INTRODUCTION

Concretions of iron sulfide from the Devono-Mississippian shales and sandstones in the vicinity of Cleveland, Ohio, have long been known. In some places, pyrite crystals could be identified easily, but in many localities nodular aggregates were found, which showed a massive compact or finely columnar radiated structure, that were not determinable by the usual methods. Similar acicular masses from other parts of the world generally have been designated as marcasite, presumably on the basis that an orthorhombic mineral might assume this habit more readily than an isometric crystal. An illustration is that of the "marcasite suns" which are disks with a radiating arrangement occurring in bituminous shales at Sparta, Randolph County, Illinois, which the present investigation proves to be pyrite. In July, 1931, when Bulletin 818 of the United States Geological Survey<sup>1</sup> was published, the occurrence of marcasite was mentioned more frequently than pyrite, especially in the shale formations. This did not conform to the few observations of the senior author of the present paper so that in October, 1931, additional specimens were collected, and an *x*-ray investigation was undertaken.

## GEOLOGY OF THE REGION

The rocks which outcrop in the Cleveland district in ascending order are: Chagrin, Cleveland and Bedford shales, Berea and Sharpsville sandstones, Meadville shale and Sharon conglomerate. The last is considered to be the basal portion of the Pottsville, and therefore is of Pennsylvanian age, while the rocks from Meadville to Berea are Mississippian. The Chagrin is definitely Devonian while the Cleveland and Bedford shales are classified by the United States Geological Survey as either Devonian or Mississippian.

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<sup>1</sup> Geology and Mineral Resources of the Cleveland District, Ohio, H. P. Cushing, Frank Leverett and Frank R. Van Horn: *U. S. Geol. Survey, Bull.* **818**, Washington, 1931.

There are breaks below the Berea, Bedford, and Cleveland, some of which are regarded as unconformities. H. P. Cushing<sup>2</sup> was inclined to place the Devonian-Mississippian boundary between the Cleveland and Chagrin shales. The maximum thickness of all of these formations is about 1500 feet. Shales of Portage age, formerly called Huron, Olentangy shale, Delaware and Columbus limestones, which do not reach the surface in the vicinity of Cleveland, are at a maximum of 1000 feet below the Chagrin, but usually considerably less.

#### METHODS OF DISTINGUISHING PYRITE FROM MARCASITE

Pyrite and marcasite are generally distinguished by differences in crystal form, color, specific gravity, and manner in which they decompose under natural or artificial conditions. Most of these methods are not very satisfactory, and not usually applicable to concretionary masses, or to mixtures of the two minerals. In 1901, a chemical method of differentiation was devised by Stokes<sup>3</sup> and was called the "Stokes oxidation method" in the classic investigation of Allen, Crenshaw, Johnston, and Larsen<sup>4</sup> which recorded every method then known for the determination of pyrite and marcasite and for their preparation by artificial means. Since 1912  $x$ -rays have been employed to distinguish these minerals. W. L. Bragg<sup>5</sup> has studied the crystal structure of pyrite while that of marcasite has been investigated by Frielinghaus,<sup>6</sup> Huggins,<sup>7</sup> and Buerger.<sup>8</sup> The most recent paper employing  $x$ -rays in the study of these sulfides is a very excellent contribution by Bannister<sup>9</sup> which describes chiefly the concretions from England, although two specimens from the United States were examined. One of these was a

<sup>2</sup> *Loc. cit.*, p. 39.

<sup>3</sup> On Pyrite and Marcasite, H. N. Stokes: *Bull.* **186**, *U. S. Geol. Survey*, 1901

<sup>4</sup> The Mineral Sulphides of Iron, E. T. Allen, J. L. Crenshaw, John Johnston, and Esper S. Larsen: *Am. Jour. Science*, vol. **XXXIII**, No. 195 pp. 169-236, 1912.

<sup>5</sup> The Analysis of Crystals by the X-Ray Spectrometer. W. L. Bragg: *Proc. Royal Soc. London*, (A) **89**, pp. 476-478, 1914.

<sup>6</sup> Röntgenographische Untersuchungen am Markasit, W. Frielinghaus: Dissert., Greifswald, 1926.

<sup>7</sup> The Crystal Structures of Marcasite, Arsenopyrite, and Loellingite, M. L. Huggins: *Physical Review* (2), **19**, pp. 369-373, 1922.

<sup>8</sup> The Crystal Structure of Marcasite, M. J. Buerger: *Amer. Mineralogist*, vol. **16**, pp. 351-395, 1931.

<sup>9</sup> The Distinction of Pyrite from Marcasite in Nodular Growths, F. A. Bannister: *Mineralogical Mag.*, vol. **XXIII**, pp. 179-187, Sept., 1932.

marcasite "sun" from Sparta, Randolph County, Illinois, which was also investigated by the authors in February, 1932, and found by all to be pyrite and not marcasite. Bannister also used mineral-graphic methods, studying the polished sections in polarized light as proposed by Schneiderhöhn and Ramdohr.<sup>10</sup> This is more rapid than *x*-ray methods and appears to distinguish definitely the two minerals but, unfortunately, the necessary equipment is not always available.

#### OCCURRENCE AND HABIT OF IRON SULFIDE CONCRETIONS IN THE CLEVELAND DISTRICT

Since October, 1931, fourteen occurrences of iron sulfide concretions have been examined. Of these, three were obtained from the Chagrin shale, ten from the Cleveland and one from the Bedford shale. There are three well-defined habits or types in which the iron sulfide is found. These are shown in Figure 1 and may be classified as follows: type 1, cubes with curved faces which sometimes occur individually but are more frequent as irregular aggregates. A sub-type was discovered in one locality in which the cube aggregates were not curved but roughened (Fig. 1, No. 1). This habit seems, therefore, to be uncommon; type 2, parallel growths or groups which consist of aggregates of curved cubes which are elongated in the direction of the trigonal axis (normal to the face of the octahedron), Fig. 1, Nos. 3-9. The most perfect is No. 8. This habit occurred in both the Chagrin and Cleveland shales, and even after more than casual inspection resembles the spear head twins of marcasite and they were assumed to be that mineral until the diffraction patterns revealed pyrite. These specimens have been shown to many mineralogists of the United States and Canada and with one exception all considered them to be marcasite. Consequently, this habit may be termed the *Pseudo-Spear Head* type, although the concretions are distinctly not pseudomorphous; type 3, the third habit is the most abundant and consists of small or large nodules which are sometimes massive compact but more usually exhibit a fibrous radiated structure (Fig. 1, No. 2). It is from concretions, sometimes containing pyrite, that many sharks and the large fish, *Titanichthys* and *Dinichthys*, have been obtained, and which have made the Cleveland shale world famous

<sup>10</sup> Lehrbuch der Erzmikroskopie, H. Schneiderhöhn and Paul Ramdohr, vol. 2, pp. 157, 192, Berlin, 1931.



from a palaeontological standpoint. In the English concretions, Bannister<sup>11</sup> concludes that the radiating masses consist of tabular or blade-like aggregates which "are elongated along a cubic axis, and flattened parallel to a cube face." There is no evidence to indicate that this applies to the concretions in the Cleveland district but it may be possible.

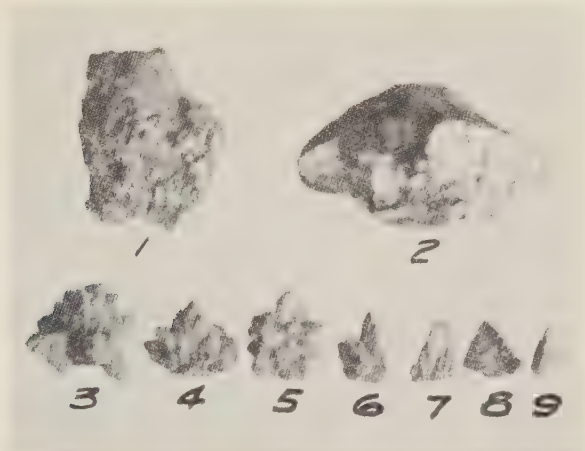


FIG. 1. No. 1. Pyrite cubes roughened but not curved (No. 1 sub-type),  $4\frac{1}{2} \times 4$  cm., Bedford shale, near Olmstead Falls, Cuyahoga County, Ohio.

No. 2. Pyrite concretion showing radiating columnar structure (No. 3 type),  $6 \times 2$  cm., Cleveland shale, Rocky River valley between "Little Cedar Point" and Olmstead Falls, Cuyahoga County, Ohio. (Figure 2, diffraction pattern No. 5.)

Nos. 3-9. Pyrite showing distorted cubes in parallel growths resembling spear head twins of marcasite, and termed "pseudo-spear heads" (No. 2 type), No. 3,  $2\frac{1}{2} \times 2\frac{1}{2}$  cm.; No. 4,  $2 \times 2\frac{1}{2}$  cm.; No. 5,  $2 \times 2$  cm.; No. 8,  $1\frac{1}{2} \times 1\frac{1}{2}$  cm. Cleveland shale, Big Creek valley, near West 130th Street, Cleveland, Ohio (Figure 2, diffraction pattern No. 4).

#### X-RAY TECHNIQUE AND PREPARATION OF SPECIMENS

Diffraction patterns were made from samples prepared by powdering the minerals. Usually the minerals were brittle and could be powdered easily in a steel mortar to pass a 300 mesh screen. The photograms did not reveal any reflections corresponding to metallic iron, thus indicating that there was substantially no contamination of the samples by iron from the mortar. The

<sup>11</sup> *Loc. cit.*, pp. 184-185.

powder was placed in one part of a Pyrex glass capillary tube, 1 mm. outside diameter, then a separating cotton plug was inserted and a sodium chloride standard was placed in the other part. The capillary tube was sealed at the extremities and centered on a General Electric cassette containing a zirconium oxide filter.

Patterns were produced by the powder method on a General Electric apparatus equipped with a molybdenum target tube ( $K_{\alpha}$  radiation), operating at 30,000 volts and 20 milliamperes. The exposure periods were 48 hours with Eastman diaphax films and the samples were rotated occasionally during this period. In measuring the positions of the diffraction lines, corrections were made

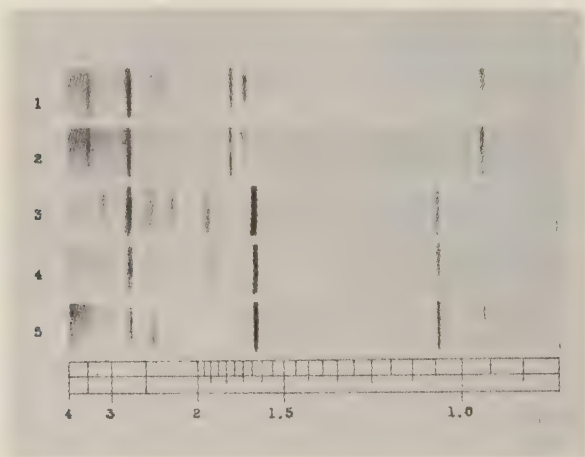


FIG. 2. Diffraction Patterns of Pyrite and Marcasite.

No. 1. Marcasite of greenish-yellow color having basal pinacoid and rounded prism which sometimes forms the aggregates called cockscomb pyrites. These crystals are associated with galena, and sphalerite on jasperoid, Joplin district, Missouri.

No. 2. Marcasite, spear head twins probably consisting of macro and brachydomes. Lower part of Olentangy shale (Middle Devonian), Delaware, Ohio.

No. 3. Pyrite with striated cube and pentagonal dodecahedron, Leadville, Colorado.

No. 4. Pyrite showing distorted cubes in parallel growths resembling spear heads and called here "pseudo spear heads" (No. 2 type), Cleveland shale, Big Creek valley, near West 130th Street, Cleveland, Ohio (same as Nos. 3-9, Fig. 1).

No. 5. Pyrite concretion showing radiating columnar structure (No. 3 type), Cleveland shale, Rocky River valley between "Little Cedar Point" and Olmstead Falls, Cuyahoga County, Ohio (same as Fig. 1, No. 2).

for any dimensional changes in the film by reference to the sodium chloride pattern, which was recorded on each photogram. The various reflections were rated as to intensity, five degrees of intensity being recognized.

Photograms were prepared from seven other massive or radiating concretions occurring in the Chagrin and Cleveland shales, and all gave the pyrite pattern. However, it is to be noted that Figure 2, No. 2 is the marcasite pattern obtained from the Olentangy shale of the middle Devonian, which is several hundred feet below the Chagrin, and over one hundred miles from the Cleveland Quadrangles.

#### CONDITIONS OF FORMATION OF PYRITE AND MARCASITE

The conclusions of Allen, Crenshaw, Johnston and Larsen<sup>12</sup> were that marcasite forms under acid and fairly low temperature conditions, while pyrite originates in solutions containing no free acid and possessing a temperature that may be low but is generally high. Since the concretions in the Cleveland district were formed later than the enclosing rock, it is evident that different conditions prevailed during the deposition of pyrite than in the Olentangy shale at Delaware, Ohio. Allen *et. al.* state "that it is pretty generally believed that organic matter of certain shales acted as a precipitant of the pyrite they contain." These investigators tried to reduce ferrous sulfate with starch and glucose at 300°C. without success. They also discussed the probable action of hydrogen sulfide and the role of micro-organisms causing precipitation. Pyrite certainly is more abundant in the Cleveland shale which is characteristically black in color, containing carbon up to 11%, and petroleum up to twenty gallons per ton. One of the diffraction patterns was obtained from massive pyrite in a concretion which contained the large Devonian fish, *Titanichthys*, which indicates the association of organic matter, and possibly hydrogen sulfide and micro-organisms as well.

An analogous condition was observed by the senior author at Heidelberg, Germany, about 1896. A mouse was drowned in a Daniels cell containing ferrous sulfate, and when found, the surface, at least, was coated with iron sulfide exhibiting a light-brass yellow color and metallic luster. Since ferrous sulfate acts acidic, and the reaction occurred at a low temperature, we are inclined to

<sup>12</sup> *Loc. cit.*, pp. 190-192.



conclude that it was a "marcasite mouse," and that the reduction was presumably caused by hydrogen sulfide.

#### SUMMARY AND ACKNOWLEDGMENTS

The results of crystallographic observations and  $x$ -ray analyses show that no marcasite has been found, as yet, in the iron sulfide concretions in the Chagrin, Cleveland, and Bedford shales of the Cleveland district. However, the Olentangy shale of the middle Devonian at Delaware, Ohio, which is several hundred feet below the formations referred to, does contain marcasite.

The authors are indebted to R. L. Barrett and Professor J. E. Hyde for assistance in the collection of specimens, and to C. M. Tucker for preparing the photograms, and the Aluminum Company of America for the use of the  $x$ -ray equipment.

## MERCURY IN NATIVE SILVER

W. H. NEWHOUSE, *Massachusetts Institute of Technology.*

The presence of silver amalgam in a number of mining districts has been known for many years.<sup>1</sup> In the amalgam the mercury content varies considerably reaching at times about 73%.

That mercury in small amounts is present also in native silver of a considerable number of the localities which produce this metal has apparently not been recognized. In specimens of native silver examined by the writer mercury was found to be present in a majority of the districts.<sup>2</sup>

New information on such occurrences when considered together with published data, suggest relationships in metals and types of mineral deposits which seem worthy of mention.

A striking feature in the occurrence of silver amalgam, comparatively rich in mercury, is the common association with cobalt or cobalt and nickel arsenides, or as a constituent of mercury deposits such as cinnabar. The latter are represented by its presence in the deposits of Almaden, Spain<sup>3</sup>; in the Ober-Moschel, Bavarian Pfalz mines in Salzburg, Rosenau, Hungary; at Brezina, Bohemia; and from the Bergmannswohlfahrt mine, Clausthal, at which place it is found with galena, cinnabar and quicksilver.<sup>4</sup> Silver amalgam is reported also from Moschellandsberg, Palatinate, where veins of mercury and silver intersect. It likewise occurs in the veins at Nagolnij Krjasch, Donetz basin, Russia.<sup>5</sup> Here it is found in the oxidized zone. The veins carry galena, sphalerite, some cinnabar, but no nickel or cobalt. It is found with cobalt, or cobalt and nickel arsenides, or arsenates, in the provinces of Atacama and Coquimbo, northern Chile; formerly an important silver producing region. Several of the mines contained silver amalgam which was very rich

<sup>1</sup> Stelzner, Bergeat, *Die Erzlagerstätten*, pp. 694, 624–34, 1905–1906.

Dana, E. S., *System of Mineralogy*, pp. 23–24.

Hintze, C., *Handbuch der Mineralogie*, vol. 1. pt. 1. pp. 322–326, 1904.

Doelter, C., *Handbuch der Mineralchemie*, vol. 3. pt. 2. pp. 364–373, 1926.

<sup>2</sup> Mercury was tested for by heating one-half gram to one gram of the native silver in a small closed glass tube. Small globules of mercury collect on the walls of the tube, and may be readily identified under a binocular microscope. Several confirmatory microchemical tests were made by converting the mercury into HgI<sub>2</sub>.

Chamot and Mason, *Handbook of Chemical Microscopy*, vol. 2, pp. 142–3, 1931.

<sup>3</sup> Hintze, pp. 323–24.

<sup>4</sup> Dana, p. 24.

<sup>5</sup> Samojloff, J., *N. Jahrb. Min.*, pp. 191–198, 1907.

in mercury.<sup>6</sup> The associated mineralization contains both cobalt and nickel. Similar relationships in regard to cobalt and nickel minerals are to be found at Allamont, Frankreich.<sup>7</sup> The silver at Cobalt, Ontario, contains mercury<sup>8</sup> in amounts reaching at times several per cent. The natural silver-antimony alloy appears to contain higher percentages of mercury than does the more pure silver. Cobalt predominates over nickel in ores from this district.<sup>9</sup> Similarly at South Lorraine, Ont., where cobalt again appears to predominate<sup>10</sup> over nickel, mercury was found by the writer in a heavy plate of silver-dyscrasite from the Frontier Mine. The native silver from the Keeley mine was known also to contain mercury.<sup>11</sup> A heavy plate of native silver from Gowganda was found by the writer to give a mercury test. Ores from the Silver Islet Mine on the north shore of Lake Superior likewise contain mercury according to Miller.<sup>12</sup> The writer found mercury in the native silver from this mine. Nickel and cobalt minerals are both present. Silver associated with cobalt arsenides<sup>13</sup> from Great Bear Lake, N.W.T., contains mercury, while very thin plate-like veins of native silver in the highly oxidized wall rock from the same region contained none. At Sala, Sweden, silver amalgam rich in mercury is found in veins carrying a silver-zinc-lead mineralization.<sup>14</sup> Some niccolite is also present.<sup>15</sup> Vogt<sup>16</sup> mentions the presence of cobalt in the veins at Kongsberg, Norway, which are noted for their production of silver amalgam.

At the Friedrichsségen Mine, Ems,<sup>17</sup> the silver amalgam is a

<sup>6</sup> Domeyko, Sur les mines d'amalgame natif d'argent d'Arqueros, au Chile: *Ann. des Mines*, 3, **XX**, pp. 255-278, 1841.

See also Stelzner and Hintze.

<sup>7</sup> Hintze, p. 324.

<sup>8</sup> Clevenger, G. H., *Econ. Geol.*, vol. **X**, pp. 770-773, 1915.

<sup>9</sup> Miller, W. G., Ontario Bureau of Mines, vol. 19, pt. 2, pp. 32-35, 1913.

<sup>10</sup> Knight, C. W., *31st Annual Report Ont. Dept. Mines*, vol. 31, pt. 2, p. 330, 1922.

<sup>11</sup> Knight, *loc. cit.*, p. 191.

<sup>12</sup> Knight, *loc. cit.*, p. 210.

<sup>13</sup> *Loc. cit.* p. 205.

<sup>14</sup> A specimen with cobalt arsenides was kindly furnished by H. S. Spence.

<sup>15</sup> Beyschlag, Vogt and Krusch, Ore deposits, Truscatt Translation, vol. 2, pp. 771-773, 1916.

<sup>16</sup> Schneiderhöhn-Ramdohr, *Lehrbuch der Erzmikroskopie*, vol. 2, p. 153, 1931.

<sup>17</sup> Vogt, J. H. L., *Zeit. für Prapt. Geol.*, p. 118, 1899.

<sup>18</sup> Doelter, p. 366.



minor constituent, as are also millerite and linnaeite, in veins consisting predominantly of galena, sphalerite, siderite, and chalcopryrite. Silver from the Lake Superior copper desposits was found to contain mercury. Also heavy wires and plates of native silver from Helena, Montana, which are partly enclosed in a one inch scalenohedron of calcite, contain mercury.

A specimen from the Buckeye Mine, Mohave Co., Ariz., gave a strong test for mercury. This mine was at one time noted for its masses of solid silver and beautiful specimens of wire silver.<sup>18</sup> The silver examined was a tooth-like mass projecting out of a calcite gangue.

Heavy plates of silver with light colored sphalerite in calcite from La Fe, Sierra Mojada, Mexico, contained mercury; also heavy platy irregular masses in calcite from Sabinal, Chihuahua. A specimen from Sombrerete, Zacatecas, Mexico, consisting of wires in calcite with galena and sphalerite, was found to contain it. Heavy wire silver from Freiberg, Saxony, contained a small amount, as did also a mass of interlacing fine wires from the Smuggler Mine, at Aspen, Colorado.

No mercury was found, however, in the specimens described below which were examined from the following localities: Minute interlacing wires resting on quartz and calcite from Boulder Co., Colorado; wire silver with quartz from Guadalajara, Mexico. (Specimen contains some limonite.) A mass composed of filaments of silver resting on euhedral galena crystals from Horcajo, Spain; Minute hair-like matted wires forming a crust on fractured quartz from the Mexico Mine, El Oro, Mexico; Thin plates of silver resting on limonitic rock from Durango, Mexico.

A recent investigation<sup>19</sup> of native silver by metallographic methods has led to conclusions of much interest regarding temperature conditions during silver deposition. The natural silver-antimony alloy receives new attention in this work. In any final statement of the origin and constitution of the natural silver-antimony alloy at Cobalt, Ontario, and other places, consideration should be given the fact that it frequently is a silver-antimony-mercury alloy.

Beyschlag, Vogt and Krusch, *Die Erzlagerstätten*, pp. 224-226, 1921.

<sup>18</sup> Schrader, F. C., *U. S. Geol. Survey Bull.* 397, pp. 83-84, 1909.

<sup>19</sup> Carpenter, H. C. H., and Fisher, M. S., A metallographic investigation of native silver: *Bull. Inst. Min. & Met.*, No. 330, pp. 1-22, Mar. 1932; No. 335, pp. 9-14, Aug. 1932.

Comparisons with the diagram of the silver-antimony system may be to some extent misleading.

#### RELATION OF AMOUNT OF MERCURY TO TYPE OF ORE DEPOSIT

The data recorded in literature and the evidence obtained in the present investigation indicate that the percentage of mercury to silver varies somewhat in a single district, or mine, or even in a single specimen. However, it is clear that the silver amalgam which is richest in mercury is, in general, found in deposits with cinnabar, or in others of a radical different mineralogical type, that is with cobalt and nickel minerals. Smaller amounts in general are found in other types of silver deposits.

It may be suggested that the mercury deposits, where cinnabar is the chief mineral, and cobalt-nickel deposits containing silver amalgam, are both derived from basic igneous rocks at different stages or along different lines of differentiation. The genetic relation of cobalt and nickel arsenides with the basic end of the rock series has received attention before.<sup>20</sup>

#### ORIGIN OF AMALGAM BY HYPOGENE SOLUTIONS

Most of the silver which contains much mercury is probably of *hypogene* origin. There can be little doubt of it in the material examined from Cobalt, South Lorraine, and Gowganda, Ontario; Kongsberg, Norway; Lake Superior Copper deposits and Silver Islet. The relations between the silver and calcite scalenohedron from Helena, Montana, appear to indicate that the silver, at least in part, preceded the deposition of the calcite. On the other hand, where the silver exhibits features indicating a *supergene* origin, mercury, as a rule, was not found. These occurrences included fine wires matted to form thin plates in open fractures and in open cavities, and draped over limonitic material, obviously of later age than the formation of the limonite surface.

According to Miller at Cobalt<sup>21</sup> "characteristically the native silver of the area is impure, chiefly from the presence of antimony and mercury. Samples of well crystallized silver and certain vein-

<sup>20</sup> Miller, W. G., *Ont. Bur. Mines Report*, vol. 19, pt. 2, 1913.

<sup>21</sup> Miller quoted by Knight, *31st Ann. Rept. Ont. Bur. Mines*, vol. 31, pt. 2, p. 37, 1922.

lets of the mineral that have been examined are free from these impurities. Such silver is probably of secondary origin."

These relations are only suggestive since the material examined by the writer is of uncertain origin. They may merely indicate that mercury is not carried in the solutions, or that the temperature is too low for it to enter the crystal structure, when fine wire silver is deposited. The determination of mercury is easy and quickly carried out. The suggestion inherent in the data so far known, that mercury is perhaps only found in hypogene silver, could be readily checked in mines where the geological relations are certain. It is known that silver may be carried in carbonate and bicarbonate solutions or in sulphate solutions with ferric sulphate.<sup>22</sup> These solutions which may be effective in the movement of silver in the oxidation processes, are not effective in the case of mercury.<sup>23</sup> Chloride solutions however, will readily carry mercury in the supergene zone. These solubility relations may be interpreted as lending some support to the idea that silver amalgam is largely deposited by hypogene solutions.

<sup>22</sup> Emmons, W. H., *Bull.* **625**, pp. 251-265, 1917.

Bastin, E. S., *U. S. Geol. Surv. Bull.* **735**, pp. 152-154, 1923.

<sup>23</sup> Broderick, T. M., Secondary enrichment of mercury deposits, *Econ. Geol.*, vol. 11, pp. 645-651, 1916.



## A DAY IN A CEYLON GEM FIELD

JOSEPH L. GILLSON, *Wilmington, Delaware.*

In March, 1932, having two free days between steamers in Colombo, Ceylon, I made arrangements to quickly visit Ratnapura, 55 miles southeast of Colombo, the center of the gem-washing industry of the island. A hired Buick "saloon" made the journey in about three hours, over a well paved but narrow and winding macadam road, leading at first through rice fields and coconut groves, but with an increase in the elevation, through rubber and tea plantations. Comfortable accomodation in a delightful location was available at the Government Rest House just outside of Ratnapura, and a guide was found who promised to show me the few garan idamas (washing places) that were still in operation during these depression days.

That the Ceylon gem fields have been known for a very long time is indicated by the fact that Friar Odoric who travelled in the East from 1316 to 1330 described them, and "that literary pirate and arch liar of the fourteenth century, Sir John Mandeville, plagiarizes the tale in a more interesting manner."<sup>1</sup>

Ratnapura (a Singhalese word meaning "City of Gems") is shown on Sheet L 19, 20, 24, 25, an excellent topographic map of the Ceylon Survey, on a scale of one mile to the inch, a copy of which I had previously purchased at the Surveyor General's office in Colombo, for rupees 2.10. A more general map of the gem bearing districts is given in the Administration Report for 1904, Part IV. Although the center of the industry, Ratnapura is actually in the northern part of the area of the deposits, which extend south nearly as far as the coast at Galle. I had been informed that most of the southern part of the district was inactive, but that I would be able to see a typical operation at Pelmadulla, some 12 miles southeast of Ratnapura.

Dr. Frank D. Adams visited the Pelmadulla<sup>2</sup> district on his trip around the world a few years ago, and described the district, and the gem operation in some detail.<sup>3</sup> The following description is

<sup>1</sup> Ball, S. H., Early gem mining, real and otherwise: *Mining and Metallurgy*, vol. 9, p. 490, November 1928.

<sup>2</sup> Adams spells this name Palmadulla, but the spelling Pelmadulla is that used on Coomaraswamy's map.

<sup>3</sup> Adams, F. D., A visit to the gem districts of Ceylon and Burma: *Annual Report of the Smithsonian Institution*, 1926, pp. 297-318.

based on my own observations and on the account of Adams and the government report by Coomaraswamy.<sup>4</sup>

Ratnapura lies in a deep valley at the junction of the Denawak Ganga with the Wey Ganga rivers, in a region of mature topography. The underlying rock is a diorite(?) gneiss, with very prom-

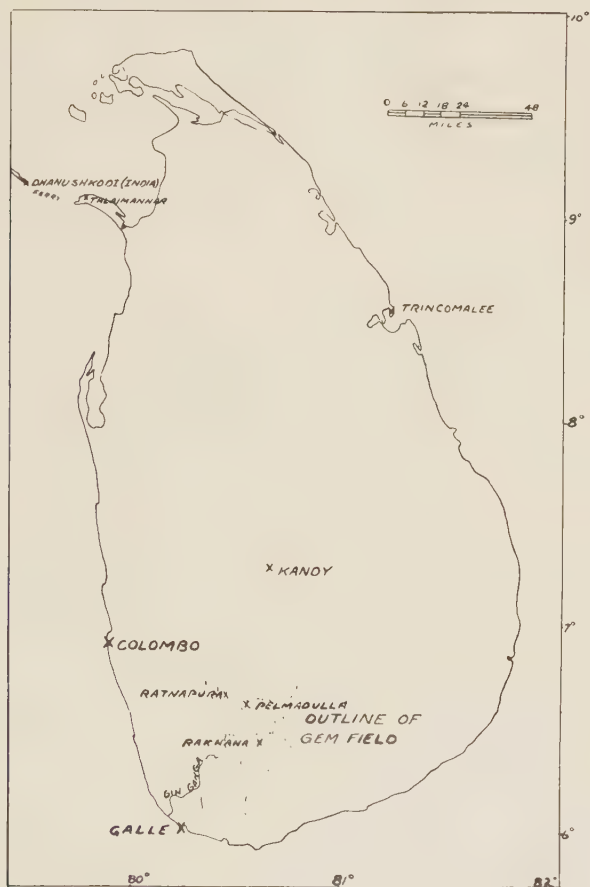


FIG. 1. Map of Ceylon showing location of gem field.

inent gneissic structure, and conspicuous drag folding. The surrounding ridges and hills, many of which are sharp peaks with shear cliffs, rise to elevations of 2750 feet, and up, culminating in

<sup>4</sup> Coomaraswamy, A. K., Report of the Director of the Mineralogical Survey: *Administrative Report*, 1904, pp. E 11 to E 19.

Adams Peak, 10 miles to the northeast, which has an elevation of 7360 feet. The Ganga rivers at their junction are flowing below the 100 ft. contour, and are muddy shallow streams during the dry season, but become raging torrents in the wet season, and often cause serious floods.

The wide flood plains of the rivers and creeks, the so-called deniyas, are the sources of the gem gravels. The surface of these plains, where not worked over and over during the gemming operations, is used as paddy fields. No washing was noted in any of the creeks themselves, but in the Administration Report, above mentioned, by Mr. Coomaraswamy, it is stated that in the small hill streams that are swift flowing, rich deposits of gem minerals are found in the river beds. In those deniyas I visited, the low water level of the creek was ten to twenty feet below the alluvial flats, or flood plain surfaces. No higher level terraces were noted.

The gem gravel, or illam,<sup>5</sup> lies just above the decomposed rock surface, or malawa, at the bottom of the flood plain, and below typical alluvial material of sand and clay. The illam was obviously a placer deposit formed in the bed of the river, when it was occupying a different channel than it now uses. This process of shifting its channel and building a wide flood plain is of course the familiar operation of any stream that has cut down to grade and has begun to meander, as it erodes laterally. In the deniyas I visited, the alluvium in the flood plains did not exceed thirty feet, but Mr. Coomaraswamy states that a maximum of 120 feet has been noted. Two layers of illam have been described, separated by sand or clay, called makul, and represent deposits at two different stages in the development of the alluvial flat, the younger one having formed after the bed of the river had silted up several feet. That the lower bed is the richer in such cases may be explained by the fact that at the later, more sluggish stage of the river, conditions for forming a placer deposit of heavy minerals, was not so favorable.

The illam is a deposit of white quartz pebbles, ranging in size from that of shot, up to boulders as large as footballs, in which are mixed the heavy and gem minerals of the placer deposit. When removed from a gem pit, however, it has become so mixed with mud that has settled out in the pit, that a pile of illam resembles a pile

<sup>5</sup> The phonetic English equivalent of Tamil and Singhalese words here given are taken from the report by Coomaraswamy.



of sticky clay rich in mica and it is not until it is washed that the gravel appears.

The largest operation examined was that near Pelmadulla, where the Rada Ela and Kirindi Ela come together to form the Denawak Ganga. There a large alluvial flat, over a quarter of a mile wide lies between the steep slopes of the ridges. On the topographic map referred to, the locality may be found at a secondary road that turns north off the highway to pass the Ganegama School. One pit was in operation just west of this secondary road, another at the edge of the plain three or four hundred yards south of the highway, opposite the secondary road, and five closely spaced pits on the north side of the highway, one hundred yards or more east of the secondary road.

Adams gives this interesting information about Pelmadulla:

"Much attention has recently been directed to the gem fields at Palmadulla about 12 miles in a southwesterly direction from the town of Ratnapura, on account of a remarkable 'find' made there a couple of years ago, sapphires and other gems to a value of some 9 lakhs of rupees (\$297,000) having been taken from an area of between 3 and 4 acres in extent in a certain paddy field. These included some very large fragments of excellent blue sapphire 1 and 2 pounds in weight, as well as fine yellow sapphires and other less valuable stones."<sup>6</sup>

The operation of gemming is as follows: A patale or shaft is sunk in the alluvium. All those that I saw, except one, consisted of two compartments. Such a double compartment shaft is roughly 15 feet long, and 7 feet wide. The shaft timbers are of bamboo, and the walls are lined with split bamboo, backed by palm leaves to exclude the water. The tools used in sinking the shaft are: a heavy hoe-like tool used throughout India and Ceylon for every possible purpose involving digging or shoveling, called in Tamil "mamoty" or "momiti,"<sup>7</sup> and in Singhalese "udella"; and the "illamkura," a light crowbar used for loosening the hard earth and illam.

Hoisting the earth is done in one of two ways. There is either a windlass by which factory made kegs, or old 5-gallon petrol tins or baskets are raised, or there is an andiya, which is a long counter-

<sup>6</sup> Adams, F. D., *Op. cit.*, p. 300.

<sup>7</sup> The first spelling is from Coomaraswamy; the second was given in a "Self Study Course" in Coolie Tamil which I used in South India. Every writer has his own ideas of the phonetic English for native words.

poised pole, supported on a high fulcrum, made of bamboo framework, by means of which the kegs or tins which hang by a rope from an end of the pole are raised or lowered. Anyone familiar with old New England and French Canadian farms has seen similar mechanical devices constructed to raise a bucket of water in the well, and the invention presumably antedates our Colonial history by several thousand years.

When the pay zone of gravel, or *illam*, is reached, the sand is stirred up with some water, and the shaft is then allowed to fill with water. This causes the "slimes" to be taken into suspension, and represents a first step in the washing of the gravel. The water is then baled out, a gang of Tamil coolies, hired in South India, turning on the windlass, or pulling on the pole of the *andiya*. In most of the *patales* near *Pelmadulla*, the operations were very modern, only windlasses and factory built kegs of about twenty gallon capacity being used, with two kegs to a windlass, operated by cranks at each end. A bamboo shelter erected over the shafts protects the coolies from the sun.

When the water is baled out, the *illam* is raised in the small baskets holding about a half bushel, and piled in a heap, inside a "cajan" fence (made of woven leaves of the coconut palm), and covered with palm leaves, the enclosure being close to the hut of the *maestrie*, or foreman. Any attempt at theft would involve a removal of the palm branches, which would be heard by the foreman. A small altar is erected near the spot, and before the *illam* is raised an offering is made, usually to *Saman Dewiyo*.

After the *illam* in the bottom of the shaft is exhausted, mining laterally into the bed of *illam* from the shaft is practiced, but in most places can not be carried far owing to the heaviness of the ground.

When the washing is to be done in the bed of the river, boys carry small baskets, called *punchi kude*, which are filled with *illam* from the stock pile, to the creek edge, where it is dumped into a wooden mixing box, resembling the type used by American plasterers in mixing mortar. There the sticky gumbo is made up into a paste, with water, so that when washed, lumps will not form. When ready, a dozen coolies wade into the creek carrying the *garan kude*, or gemming basket—a sort of "gold pan." It is a conical shaped basket, of woven fiber, with a stout rim, roughly 28 inches in diameter, and 15 inches deep. The mesh of the basket is sufficiently

loose so that fine sand and slime can be readily washed through the openings.

Two coolies stand between the bank and the circle of waiting "panners." The mixing man tosses a dripping basket of mush to the first boy who skillfully catches it, at the same time tossing back an empty basket, the two baskets passing in mid air, like the trick balls of a vaudeville performer. The second boy throws an empty basket, catching a full one which he in turn passes to one of the "panners." The panners begin a panning action, holding the *garan kude* immersed in the river, with only the rim partly above water. As the quantity of *illam* is reduced, more is added until a sufficient, or lucky number of small baskets-full have been received. Fifteen or twenty-one are considered lucky numbers. The panning action is prolonged, (about 10 to 15 minutes) until all of the fine sand, and the light minerals have been washed through the openings, or out over the rim, leaving only the heavy minerals, and some limonite concretions.

Each "panner" now wades ashore, and dumps the quart or two of heavy concentrate in his *garan kude*, into one basket. When all have been dumped, the foreman squats before it, and paws quickly through the mass with his fingers, his sharp eye at once spotting any stone of value. The foreman at the *Pelmadulla* operation was a young Singhalese man of intelligent appearance who, clad in a dhoti and shirt, and sporting a wrist watch, but of course barefoot, took no part in any menial tasks, for in the East a man either works with his hands or his brain—never with both. Watching him in two successive examinations of the concentrate, I saw him select a yellow sapphire crystal, of possibly 30 carats weight, but of poor quality from the first batch, and two valueless spinels and an inferior *cats-eye* from the second.

I attempted to buy the inferior quality stones I saw recovered, but was informed that as the men worked on shares, they would not be content to sell any stone, until it had been properly appraised.

The concentrate from which the gems have been picked is known as *nambuwa*. It is an aggregate of small rubies, sapphires, spinels, tourmaline, ilmenite, rutile, garnet and other heavy rock silicates. Much of it has value for the content of thorium minerals it may contain (thorianite and thorite) but the *nambuwa* was not being saved at the operation I saw.

Adams says that the working on shares is apportioned as follows. The owner of the paddy field gets one fifth of any profits, the man who finances the operation another fifth, the remainder going to the men who carry out the actual work.

Stones are sold at auction in the bazaars, principally at Ratnapura, on special days. The gem dealers are said to be "moormen," that is, Tamils converted to Mohammedanism who have migrated to Ceylon from India. Ratnapura is also the center of much lapidary work, although by no means all of the stones are cut before they are sold. The lapidary work is exceedingly prim-



FIG. 2. A lapidary at work in Ceylon.

itive, but the men are very skillful. The grinding wheel consists of a vertical metal disk, running on a horizontal shaft, motivated by a contrivance like a violin bow. The string of the bow is given one turn around the shaft, and as the bow is pushed forward and backward by the right hand, the shaft is whirled, first one way and then the other. The stone is held in the left hand, or mounted on a wooden dop, held in the hand, without any support or guide. The selection of the facets is entirely done by eye, and the results of such



free hand work is remarkable in the uniformity of the facets, their number, and the smoothness of the planes.

Sawing the crystals, to select portions to be cut, is done by a hand hack saw, using carborundum, or alundum, as the abrasive medium. The time required to saw through a large corundum crystal in this way would overtax the patience of a European, but time is of no importance in the East.

Formerly the lapidaries prepared their own abrasive, from corundum dust, called Kurundugal, but I was told that all is now bought and is of German manufacture.

The gem placers of the Ratnapura district yield a remarkable assortment of stones, and any or all may be found in a single deniya. Those listed by Coomaraswamy are as follows: sapphire, ruby, topaz, cordierite, beryl, spinel, chrysoberyl, garnet, tourmaline, zircon, and quartz. The moonstones of Ceylon do not come from the gem gravels, but are obtained by quarrying a peculiar adularia bearing leptynite in the Dumbara district of the Central Province. (See Ceylon Administration Report, Mineralogical Survey, 1903, p. 10).

As to the source of the gem stones, Adams <sup>8</sup> quotes J. S. Coates, Esq., B.A., the present Government mineralogist as believing that the various forms of corundum originate in quartz-free pegmatites cutting the gneissic series. The beryls have been seen in quartz pegmatites and the zircons have their origin in the same rock. Coomaraswamy states that most of the gems have not as yet been found in their original matrix. Wayland<sup>9</sup> has postulated the source of the several gems and thinks that the spinel has come from lime-stones and intrusive mica-spinel rocks, and the cordierite, garnet, etc., has come from the gneisses and schists. It seems very possible to the writer that the crystalline complex may contain some calcareous layers, and the whole cut by many pegmatites of varying character.

The sapphire varies from deep blue to yellow, to colorless. A pink or flesh colored variety is sold as "King Topaz." The star sapphire is the most valuable stone found in the gravels, if of high quality. The rubies are inferior to those from Burma. Star rubies are common, and of no great value. The cats-eye, a variety of

<sup>8</sup> Adams, F. D., *op. cit.*, p. 299.

<sup>9</sup> Wayland, E. J., Notes on the sources of origin of Ceylon Gem-Stones: *Econ. Geology*, vol. 18, pp. 514-515, 1923.

chrysoberyl, with an irridescent line, or lines, is also highly prized. Chrysoberyl also occurs as alexandrite. The "aquamarine" of Ceylon includes both green topaz, and pale beryl. A true emerald color is extremely rare. White topaz is sold as water sapphire, although the true water sapphire of Ceylon is cordierite and seems to be very rare. The majority of the stones described as toramalli (a Singhalese word from which we have taken tourmaline) are zircons (from the Arabic zaqun—called in Tamil jargon). They are of various colors: green, yellow, pale brown and red. Pale brown zircons are burned to form the colorless "Matara diamond." Many green stones acquire a good yellow color when burned. The term Mangu toramalli is applied to genuine brown tourmaline. Quartz occurs as rock crystal, and as amethyst.

There is said to be some business in importing German synthetic stones, and mixing them with the parcels of native gems, against which the wary purchaser must be on his guard.

## PROCEEDINGS OF SOCIETIES

### PHILADELPHIA MINERALOGICAL SOCIETY

*Academy of Natural Sciences of Philadelphia, March 2, 1933*

President Trudell presided at a stated meeting of the society, with 48 members and 43 visitors present. Dr. Joseph L. Gillson was elected a member.

Dr. Frederick M. Oldach of the University of Pennsylvania described "The French Creek Orebody." Geologic details were given, and the results of a study of the various stages of mineralization, and the mineral sequences. While the mines are now abandoned, the dumps still yield specimens. A chalcopyrite crystal one and a half inches long was found last year.

W. H. FLACK, *Secretary*

### MINERALOGICAL SOCIETY OF GREAT BRITAIN AND IRELAND

MINERALOGICAL SOCIETY, March 23rd, 1933. SIR JOHN S. FLETT, President, in the chair.

DR. L. J. SPENCER: *Biographical notices of mineralogists recently deceased* (fifth series).

MR. MAX H. HEY: *A possible source of error in the determination of symmetry from optical extinction-angles*. In certain cases a small departure of a cut plate from the intended section direction may lead to comparatively large errors in the extinction angle and hence to an incorrect determination of symmetry. This is well illustrated by mesolite.

MR. MAX H. HEY: *Studies on the Zeolites. Part V. Mesolite*. New analyses and x-ray studies of mesolite indicate that the correct formula is  $\text{Na}_4\text{Ca}_6\text{Al}_{16}\text{Si}_{24}\text{O}_{80} \cdot 22\text{H}_2\text{O}$ . There is often a slight replacement of Na by K, and generally an appreciable replacement of Ca by 2Na. The axial ratio has been determined by goniometric and x-ray methods. Refractive index, birefringence and optical axial angle measurements have been made. The vapor pressure has been studied by the isohydric method previously described. A number of base exchange products have been prepared and the potassium and lithium derivatives shown to be identical with those obtained from natrolite. This provides the first conclusive proof that mesolite and natrolite are, as has been commonly assumed, isostructural. X-ray photographs of mesolite are very similar to those of natrolite, but show distinct differences. The space-group is  $\text{C}_2'$ .

DR. A. E. MOURANT: *The dehydration of thomsonite*. A study of the dehydration of thomsonite by the isobaric method. The results, obtained some years ago, are supplementary to those obtained by Hey by the isohydric method and differ from them in some respects. Dehydrated thomsonite does not absorb air. The lattice-shrinkage reaction has been further investigated.

MR. F. J. TURNER: *Note on the occurrence of piedmontite in quartz-muscovite-schist from the Shotover valley, western Otago, New Zealand*. The description of piedmontite in schist occurring as boulders in the Shotover river. The mineral has not previously been recorded from New Zealand.

## BOOK REVIEWS

KRISTALLOMETRISCHE DETERMINEERINGS-METHODEN. JAN HENDRIK HAAN. Proefschrift Univ. Groningen. J. B. Wolters, *Groningen*, 1932, 178 pp. Illustrated, 18×25.5 cm.

In this book Haan has tabulated and classified the geometric constants of 950 chemical compounds according to the method proposed by Barker. The tabulated values were recalculated from the data in Groth's *Chemische Krystallographie*. Haan has accomplished a substantial fraction of the work required to prepare determinative tables of geometric properties of all measured compounds, now numbering about 8000, and the present descriptions are intended as the beginning of a complete systematic catalogue of all measured crystals.

In 45 pages of text Haan discusses the proposals that have been made for the erection of systems of classification of the geometric properties of crystals to be used for the purpose of identification of an unknown compound. The systems explained and discussed are the ones proposed by Frankenheim, V. Goldschmidt, V. Goldschmidt and S. G. Gordon, Fedorov, Boldyrev, Barker. He concludes that the method proposed and tried out on a limited scale by Barker is the best and that it is, moreover, very satisfactory. With this method, as shown by Haan, Barker, and others, different observers will orient the same crystal in the same way and will obtain the same axial ratio from it. Haan points out at the same time that different crystals of the same compound grown under different circumstances (differences in habit) may lead to more than one orientation or axial ratio and that more than one entry in the table may be required for the same compound in some cases. Haan does not believe that such occurrences will be of sufficient frequency to seriously diminish the value of the determinative method, however.

The question has recently been discussed privately by several American crystallographers whether the axial ratio of a compound recorded in a set of determinative tables for use with the reflection goniometer should necessarily be exactly the same as that obtained from the unit cell dimensions established by *x*-ray analysis, or whether the axial ratio recorded in the tables might in some cases differ from the latter as some whole multiple. Barker himself states that it is not necessary for the axial ratio determined by his method to agree exactly in all cases with the unit cell dimensions determined by *x*-ray analysis. The present writers also believe that it is not desirable to stretch the results of the two methods of inquiry, with the reflection goniometer and the *x*-ray goniometer, into exact correspondence, although there should be a simple relation between them in all cases and an exact correspondence in many.

We think also that some day it may be possible to assemble a determinative table of unit cell dimensions determined by *x*-ray analysis in which only one entry will be required for each chemical compound. When that time arrives, however, it will still be true, in most cases, that a determinative investigation can be made more quickly with the reflection goniometer than with the *x*-ray goniometer. Therefore, we see no reason why two such tables, the one of geometrical constants and the other of unit cell dimensions, should be made to correspond exactly in all cases. It seems likely that an attempt to achieve a complete correspondence might lead to the frustration of both determinative methods.

GEORGE TUNELL  
TOM. F. W. BARTH



A DESCRIPTIVE PETROGRAPHY OF THE IGNEOUS ROCKS, VOL. II. THE QUARTZ-BEARING ROCKS. ALBERT JOHANNSEN. Pp. 428. The University of Chicago Press, *Chicago*, 1932,. Price \$5.50.

The second volume of Johannsen's scholarly work describes the quartz-bearing rocks from silexite to quartz-calcicase-gabbro. One is pleasantly impressed at the ease with which Johannsen's quantitative classification fits the Rosenbusch classification, how few new names are introduced and how obvious are the meanings of nearly all the names to one reasonably familiar with the Rosenbusch classification.

The descriptions are excellent—brief but adequate—and they are usually preceded by an interesting discussion of the historical development of the name and numerous references to the literature. Quaint quotations in the footnotes and interesting human touches add spice to the pages.

The quantitative mineral composition and the chemical analysis are given of all the rocks for which the former data are available. This should prove of great value to all petrographers and should encourage the publication of more such data.

In addition to the purely descriptive sections there are occasional discussions of the origin of some features such as rapakivi structure. Orbicular structures are treated at length under several rock types. There is a good discussion of the weathering of the various rocks.

Criticism of such a book as Johannsen's is likely to be largely a matter of the reviewer's personal preferences. The present reviewer objects to the term *kali-as* as a prefix for a rock in which there is more soda than potash. The average *kali-granite* (page 56) has more soda and less potash than the average *sodaclase-granite* (page 112). In general, it would be well to give more consideration to the chemical composition of minerals and mineral aggregates, even though it cannot be determined under the microscope. When the hand specimen study is not sufficient, we use the microscope, and when the microscope is not sufficient we must use a chemical analysis or any other means available for the complete analysis of the rock. Thus, the soda and potash in microcline, sanadine, perthite and ground masses are not distinguished. In general, the groundmass of a rock must be understood as well as the other constituents, even though it is a glass. This can commonly be done with a microscope by one familiar with rocks; if not, chemical means must be used and they must be taken into account in the rock classification. In that case, the effusive rocks would have the same chemical composition as the corresponding plutonites.

Johannsen gives the hypabyssal rocks a position of equal importance with the extrusive rocks. Is it not better to divide the rocks on the basis of texture rather than on geological occurrence? The emphasis on *aschistic* and *diaschistic* dike rocks is of doubtful significance.

In parts of the book the author has not distinguished carefully between truly igneous rocks and a rock formed by hydrothermal alterations of an older rock, such as *tourmalite* and *greisen*. The quotations in many foreign languages will be a disadvantage to many. Would it not be better to quote these in English translations?

The book is well prepared by the publisher except that the photomicrographs are not well reproduced. When completed, Johannsen's four volumes should be the world's standard on the subject of descriptive petrography. However, the price of the four volumes is so high that few students and not many teachers or investigators can afford to own the set. Can we not find a way to keep the price of such books within the resources of those who would naturally use them? ESPER S. LARSEN

## NOTES AND NEWS

### CRYSTALLOGRAPHIC ANGLE-TABLES

C. PALACHE, L. LAForge AND M. A. PEACOCK,  
*Harvard University*

In the course of compiling crystallographic data for a new edition of Dana's System of Crystallography, angle-tables have been calculated for a number of minerals not included in Goldschmidt's Winkeltabellen. Ninety-five tables have been reproduced by planograph on loose sheets 8 inches by 10 inches, and copies of any or all of them may be obtained at the cost of reproduction ( $1\frac{1}{2}$  cents a sheet), plus the cost of mailing. A list of minerals for which sheets are available will be mailed to any one interested. Please address Miss Mildred B. Fitz, Secretary, Department of Mineralogy, 12 Geological Museum, Harvard University, Cambridge, Mass.

### ANKERITE FROM BETHESDA, MARYLAND

TITUS ULKE, *Washington, D. C.*

An apparently unrecorded locality for ankerite is the long abandoned Huddlestone Gold Mine, near Bethesda, Maryland, a few miles from the boundary line of the District of Columbia. The white, gray, or pinkish mineral forms cleavable masses nearly an inch across, and is found scattered through an altered gabbro associated with quartz, pyrite, black tourmaline and fine grained chlorite.

The refractive indices, determined by W. T. Schaller, are  $\omega = 1.694$ ,  $\epsilon = 1.510$ . These values would indicate the composition of the ankerite to be about 14 per cent ferrodolomite ( $\text{CaO} \cdot \text{FeO} \cdot 2\text{CO}_2$ ) and 86 per cent dolomite ( $\text{CaO} \cdot \text{MgO} \cdot 2\text{CO}_2$ ). The recalculated chemical analysis shows it to contain about 21 per cent ferrodolomite and 79 per cent of dolomite.

#### ANALYSIS OF ANKERITE

CaO	33.78	Equivalent to:	
MgO	13.70	CaCO <sub>3</sub>	60.27
FeO	6.57	MgCO <sub>3</sub>	28.66
MnO	0.35	FeCO <sub>3</sub>	10.59
CO <sub>2</sub>	45.69	MnCO <sub>3</sub>	0.57
	100.09		100.09
D = 2.88			

From the above data it would seem that in the analysis the CaO determination is probably slightly too high and the MgO value is correspondingly too low.

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#### DIRECTORY OF AMERICAN AND CANADIAN MINERAL COLLECTIONS

SAMUEL G. GORDON, *Academy of Natural Sciences of Philadelphia*

At the suggestion of Drs. Hugh S. Spence and Walter F. Hunt, the desirability of a directory of American and Canadian mineral collections was favorably considered by the Council and the writer was asked to assemble the necessary data. A statement concerning the proposed survey and the nature of the directory appeared in the *American Mineralogist*, *Rocks and Minerals*, the *Journal of Geology*, *Economic Geology*, the *Engineering and Mining Journal*, *Science*, and *Nature*: to the editors of those journals thanks are here given. As the response to requests for information regarding mineral collections was disappointingly small, a questionnaire was mailed to institutions listed by Merrill,<sup>1</sup> and Rea<sup>2</sup> as having mineral collections, as well as to many others in the more extensive lists of Wallace<sup>3</sup> and Minerva.<sup>4</sup> The privately printed paper by the late Frederick A. Canfield<sup>5</sup> on "The Final Disposition of some American Mineral Collections" was also useful, as was the familiar directory of Cassino.<sup>6</sup> Replies were received from about half of the institutions and private collectors to whom the questionnaire was sent.

The present directory, then, is based on first hand information from about half of the collections listed; other institutions are included in the list since Merrill and Rea mentioned them as having mineral collections. The listing of private collections, however, is based almost entirely on first hand information. Under the cir-

<sup>1</sup> Merrill, F. J. H., *Directory of Natural History Museums in the United States and Canada: Univ. N. Y. State Museum, Report 56* (4), 1903 (Bulletin 62).

<sup>2</sup> Rea, Paul Marshall, *A Directory of American Museums: Bull. Buffalo Soc. Nat. Sciences*, X (1) 1910.

<sup>3</sup> Wallace, Beatrice L., *Directory of Museums: Museum Work*, VIII, (5) 129-155, 1926.

<sup>4</sup> Minerva: *Jahrbuch der Gelehrten Welt (Berlin and Leipzig)*.

<sup>5</sup> Canfield, Frederick A., *The final disposition of some American mineral collections*, 1923.

<sup>6</sup> Cassino, Samuel E., *The Naturalists Directory*. Salem, Mass.

cumstances, it is realized that the directory is not complete, particularly with respect to private collections; but certainly the more important and active collections have been included. Visitors to mining districts will usually find small private collections in the hands of miners, in mine offices, assay offices, in hotels and pool rooms. We will be grateful for corrections and information regarding omissions.

## ALABAMA

AUBURN ALABAMA POLYTECHNIC INSTITUTE.

Collection of 1000 specimens.

SPRING HILL SPRING HILL COLLEGE.

A small general collection of about 500 specimens which may be seen upon request.

TALLADEGA TALLADEGA COLLEGE.

UNIVERSITY ALABAMA MUSEUM OF NATURAL HISTORY, INC.,  
Dr. Walter B. Jones, Director.

A general collection of about 2700 specimens may be seen in Smith Hall from 8 A.M. to 10 P.M. daily and Sunday. An 800 pound mass of celestite crystals, and a 400 pound mass from Magnet Cove containing eudialyte and other rare minerals are prized exhibits. The museum has over 10,000 duplicates. Charles Mohr of Mobile, Alabama, presented his collections of minerals and fossils to the University. Houses the Alabama Geological Survey collections and the Schowalter collection of minerals and fossils.

## ARIZONA

HOLBROOK PETRIFIED FOREST NATIONAL MONUMENT MUSEUM.

OATMAN FRANK WARNING, P. O. Box 93.

A collection of about 1500 local minerals, ores, and rocks.

PHOENIX ARTHUR L. FLAGG, P. O. Box 2246.

A general collection of 5000 specimens (now in storage).

THE ARIZONA MUSEUM.

TUCSON UNIVERSITY OF ARIZONA. College of Mines and Engineering, and Arizona Bureau of Mines. Prof. G. M. Butler, Dean and Director.

More than 2600 fine mineral specimens are on display in the Mineralogy Museum, which contains also Dr. G. M. Butler's private collection of cut gems. The collections are especially rich in Arizona minerals. The reference series numbers approximately 4600 specimens, while the working collections include 1000 crystals, and more than 20,000 minerals and rocks.



## ARKANSAS

CONWAY            HENDRIX COLLEGE, George H. Burr Museum of Natural History.

A small teaching collection of 800 minerals.

FAYETTEVILLE   UNIVERSITY OF ARKANSAS MUSEUM. Dr. Albert W. Giles, Custodian.

The museum, on the fourth floor of the main building, is open daily except Sundays, from 8 A.M. to 5 P.M. The collections, numbering over 6,000 specimens are especially rich in Arkansas minerals, particularly from nearby Magnet Cove, Hot Springs, and Crystal Mountain.

## CALIFORNIA

BARSTOW           C. E. WILLIAMS.

A general collection, including fine silver sulfides from Sonora, Mexico.

BERKELEY           JOHN MELHASE, Geologist, 675 Vincente Avenue.

A large collection comprising (a) 1000 showy crystal groups, rich in western minerals and Death Valley borates, (b) a rather complete "species" series of small specimens, (c) a crystal collection, including twin crystals and pseudomorphs.

## UNIVERSITY OF CALIFORNIA.

Only 1300 mineral specimens and 120 crystals from the extensive teaching collections are exhibited in the Department of Geological Sciences in Bacon Hall. Many California minerals are included in the collection, particularly from the nearby glaucophane schists. They may be seen weekdays from 8 A.M. to 5 P.M.

UNIVERSITY OF CALIFORNIA, COLLEGE OF MINING:  
Hearst Memorial Mining Building.

Contains the private collection of Frank H. Probert, numbering 2500 specimens.

CLAREMONT        J. D. LAUDERMILK.  
POMONA COLLEGE.

A general and local collection numbering 2000 specimens. A. O. Woodford, custodian. Open daily 9 A.M. to 4 P.M.

COACHELLA        LELAND H. DYKES, *Union High School*.

LAWS               ROBERT SYMONS, Box 118.

LOS ANGELES      CALIFORNIA STATE EXPOSITION BUILDING. Exposition Park.

The Exposition Building, open daily from 10 A.M. to 4 P.M. and on Sundays and holidays from 2 P.M. to 5 P.M., contains an exhibit of California minerals and gems, as part of the exposition of the resources and industries of the state.

HIGH SCHOOL, SCIENCE AND ART MUSEUM.  
LOS ANGELES MUSEUM, Exposition Park.

The general collection numbers about 10,000 specimens. Mr. H. R. Hill is curator. The museum is open daily from 10 A.M. to 4 P.M., and on Sundays and Holidays from 2 P.M. to 5 P.M.

MOLCALNO CHAMPION SILLIMANITE, INC.

Collection of minerals in the mine office (andalusite, dumortierite, etc.).

C. D. WOODHOUSE, General Manager: Champion  
Sillimanite, Inc.

A general collection of 2000 specimens.

MONROVIA NORMAN E. SMITH, 514 So. Ivy Avenue.

A collection of 2000 small specimens.

UNION HIGH SCHOOL.

OAKLAND WILLIAM C. DAY, 3943 Magee Avenue.

Amateur lapidary and gem collector.

OAKLAND PUBLIC MUSEUM.

JOE RUSSELL, 4123 Manila Avenue.

Choice collection of Bisbee copper minerals.

PACIFIC GROVE PACIFIC GROVE MUSEUM ASSOCIATION.

PALO ALTO LELAND STANFORD JUNIOR UNIVERSITY.

R. M. WILKE.

PASADENA CALIFORNIA INSTITUTE OF TECHNOLOGY, West  
Bridge Building. René Engel, Custodian.

A collection of several thousand specimens including that of the older Throop Polytechnic Institute, which contained the John Dickinson (of Forestville, Conn.) collection, rich in Branchville, Conn., minerals.

PASADENA JUNIOR COLLEGE.

A general collection of 5000 specimens, rich in minerals of the Pacific Southwest. Edwin F. Van Amringe, Curator.

PETALUMA M. VONSEN.

A general collection of 2200 specimens. Destined for the California Academy of Sciences.

RIVERSIDE E. J. BRYAN, 7th and Franklin Street.

FRED. PFAFF, 9th and Riverside St.

MUNICIPAL MUSEUM.

SACRAMENTO CALIFORNIA MUSEUM ASSOCIATION.

SAN DIEGO NATURAL HISTORY MUSEUM (San Diego Society of Natural History), Balboa Park.

Two thousand specimens are in the Museum, of which J. E. Morrison is curator. Although the collection is a general one, some local semi-precious gems, particularly from nearby Pala are well represented. The museum is open every-day from 9 A.M. to 5 P.M.

SAN FRANCISCO CALIFORNIA ACADEMY OF SCIENCES.

A general collection of several thousand specimens. Mr. Vonsen writes that his collection is destined for the Academy.

DIVISION OF MINES, Formerly California State Mining Bureau. Ferry Building. Custodian: Walter W. Bradley, State Mineralogist.

Over 18,000 specimens, principally from California. Crystallized gold is a feature of the display, which is open daily, except Sundays and Holidays, from 9 A.M. to 5 P.M., and Saturdays from 9 A.M. to 12 M.

H. C. FORNEY, Mining Engineer. 665 Pine Street.

Small general collection.

MEMORIAL MUSEUM. Golden Gate Park.

Stated to contain the Max Braverman (San Francisco) Collection of California minerals.

ERNEST SCHERNIKOW. 2240 Hyde Street.

Collection of small specimens mounted for the microscope.

C. N. SCHUETTE, Mining Engineer. 306 Call Building.

Specializes in quicksilver ores and minerals.

SANTA BARBARA MUSEUM OF NATURAL HISTORY.

SANTA CLARA UNIVERSITY OF SANTA CLARA MUSEUM.

THERMAL JOHN W. HILTON, Avenue 66, Highway 99.

Specializes in agate and quartz.

UNIVERSITY (Los Angeles) UNIVERSITY OF SOUTHERN CALIFORNIA.

UPLAND M. P. YAECKEL, R.F.D. No. 1.

A general collection, specializing in the gem minerals of the California pegmatites.

WILMINGTON W. S. LIVINGSTON (Coast Fishing Company).

A small collection.

YOSEMITE YOSEMITE NATIONAL PARK MUSEUM.

## COLORADO

BOULDER J. HENDERSON.  
R. D. GEORGE.  
UNIVERSITY OF COLORADO.

The Simon Guggenheim systematic collection of minerals is displayed in the Museum open daily (except Sundays) from 8 A.M. to 5 P.M. Extensive collections are also housed in the Department of Geology (Hale Building).

COALMONT F. DE LYNDON.

A collection of cut and polished rocks showing geologic structures, and of minerals and ores.

COLORADO SPRINGS LAZARD CAHN.  
COLORADO COLLEGE MUSEUM.

CREEDE BEN A. BIRDSEY.  
ALLAN CAPLAN, c/o Ben A. Birdsey.  
PARSON POOL HALL.

DENVER COLORADO MUSEUM OF NATURAL HISTORY, City Park.

More than 5500 specimens are exhibited, including spectacular crystallized gold, in the basement floor of the main section of the museum. Mr. Frank Howland is curator. The museum is open weekdays from 9 A.M. to sunset, and on Sundays from 12:30 P.M. to sunset.

COLORADO SCIENTIFIC SOCIETY.  
COLORADO STATE MUSEUM.

The John F. Campion collection.

ARTHUR G. POHNDORF, 400-17th Street.  
STATE BUREAU OF MINES, in the Capitol.

Minerals and ores of the State. Contains the John Elsner Collection.

UNIVERSITY OF DENVER.

FORT COLLINS COLORADO AGRICULTURAL COLLEGE.

The mineral collections, which include the private collection of Prof. R. G. Coffin (Custodian) number 8000 specimens, may be seen daily in the chemistry building.

GOLDEN COLORADO SCHOOL OF MINES. J. Harlan Johnson, Custodian.

The collections, especially rich in Colorado minerals (Clear Creek, Gilpin County, Georgetown, Pikes Peak, and Table Mountain) number 8000 specimens and are housed in Guggenheim Hall. They may be seen daily except Sunday.

J. HARLAN JOHNSON.

A general and local collection of 2000 specimens.



GREELEY	COLORADO STATE TEACHERS COLLEGE.
PUEBLO	EDWIN OVER, JR. 2528 Pine Street.
SPICER	J. C. McNAMARA.

Collection of ores.

#### CONNECTICUT

BRANFORD	A. E. HAMMER, M. I. F. Co.
BRIDGEPORT	BARNUM INSTITUTE OF SCIENCE AND HISTORY.
DANBURY	WILBUR J. ELWELL, Route 4, Box 20.

A general and local collection of over 1000 specimens. Not open to the general public.

GREENWICH	BRUCE MUSEUM.
HARTFORD	TRINITY COLLEGE. Museum of Natural History.

Stated to have the John H. Caswell collection.

WADSWORTH ATHENIUM. Mrs. Florence Paul Berger, General Curator.

The museum, open daily from 10 A.M. to 4 P.M., and Sundays from 2 P.M. to 5 P.M. exhibits the Henry D. Miller (Plainville, Conn.) collections of 3492 specimens in the basement.

MIDDLETOWN	WESLEYAN UNIVERSITY. Dr. W. G. Foye, custodian.
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The collections are rich in minerals from the Connecticut pegmatites (Haddam, East Haddam, Portland, and Middletown), including many collected by Prof. John Johnston. The more than 17,000 specimens include the Franckfort collection.

NEW BRITAIN	NEW BRITAIN INSTITUTE MUSEUM.
NEW HAVEN	FREDERICK S. EATON, 85 Laurel Road.

A collection of several hundred Connecticut minerals.

H. M. LEHMAN, 1705 Springfield Avenue.  
YALE UNIVERSITY, PEABODY MUSEUM OF NATURAL HISTORY.

Dr. William E. Ford, Curator. The Yale collections were begun in 1804 by Prof. Benjamin Silliman, and were later developed by Professors James D. Dana, Edward S. Dana, and Samuel Penfield. The nucleus of the collection was the George Gibbs cabinet. Later acquisitions included the collections of Hubert A. Newton, Baron Lederer, E. R. Beadle, Frederick B. Leonard, and the Blum collection of pseudomorphs. Another comprehensive collection, that of George J. Brush, is housed in the Department of Mineralogy in the Sheffield Scientific School. The meteorite collection is particularly noteworthy.

PORTLAND	FRED. E. STRICKLAND.
STAMFORD	SAMUEL C. BROWN.
STORRS	CONNECTICUT AGRICULTURAL COLLEGE.
WALLINGFORD	THE CHOATE SCHOOL.

The collection of Ray Wentworth Tobey is exhibited in part.

#### DELAWARE

NEWARK	UNIVERSITY OF DELAWARE. Fred. J. Hilbiber Collection.
WILMINGTON	IRENEÉ, DuPONT Rising Sun Lane. DR. OTTO RUNGE, 1315 Delaware Avenue. SOCIETY OF NATURAL HISTORY OF DELAWARE.

#### DISTRICT OF COLUMBIA

WASHINGTON	BUREAU OF MINES.
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Mr. R. M. Santmyers is in charge of an exhibit of economic ores and some of their products, and of building materials of mineral origin.

CATHOLIC UNIVERSITY OF AMERICA.

COLUMBIAN COLLEGE (of GEORGE WASHINGTON UNIVERSITY).

GEORGETOWN UNIVERSITY, Coleman Museum.

HOWARD UNIVERSITY MUSEUM.

MR. ELRA C. PALMER, 5608-14th Street.

A variety of minerals, including flint, jasper, chalcedony, and other types of pebbles from the bed of the Potomac.

SMITHSONIAN INSTITUTION, United States National Museum. Dr. W. F. Foshag, Curator of Mineralogy and Petrology.

Exhibited are (1) a series of 2500 specimens representing 750 species, (2) about 500 large and striking specimens, (3) the Isaac Lea collection of 5000 cut gems and carved stones, (4) the collection, in part, of Bolivian minerals loaned by Jack Hyland. In 1926 the Museum received the famous collection of the late Colonel Washington A. Roebling with an endowment, from his son Ferdinand. The Roebling collection was noteworthy because of the extraordinary number of species and varieties included in it, as well as for a number of particularly choice specimens. It was followed by the bequest, with an endowment, of the collection of the late Frederick A. Canfield, which included the cabinet of his father, Frederick Canfield (who probably inherited the earlier collection of his uncle Mahlon Dickerson). This collection contained many extraordinary specimens from Franklin, New Jersey, and Bolivia. Other collections received by the Museum were those of John T. Abert, William S. Disbrow, in part (New Jersey zeolites),

George W. Hawes, Joseph Leidy (in part), Charles U. Shepard (including his meteorites), and Walter R. Johnson (who had purchased some minerals from the collection of Henry Stephen Fox). The National Museum is the depository of the United States Geological Survey. Exhibited in another hall is the remarkable series of meteorites brought together under the curatorship of the late George P. Merrill. The mineral collection of James Smithson, founder of the Institution, was destroyed by fire, before the present museum was organized.

## FLORIDA

- DE LAND JOHN B. STETSON UNIVERSITY.  
 GAINESVILLE UNIVERSITY OF FLORIDA.  
 ST. AUGUSTINE THE CRICHLAW MUSEUM OF NATURAL HISTORY.  
 TALLAHASSEE FLORIDA GEOLOGICAL SURVEY.

A general collection is exhibited on weekdays in the Martin building.

- WINTER PARK ROLLINS COLLEGE MUSEUM

## GEORGIA

- ATHENS UNIVERSITY OF GEORGIA.  
 ATLANTA ATLANTA UNIVERSITY.  
 GEORGIA STATE MUSEUM. (Geological Survey of Georgia.)  
 BOWDOIN BOWDOIN (NORMAL AND INDUSTRIAL) COLLEGE.  
 MACON MERCER UNIVERSITY.  
 Small collection of meteorites.  
 OXFORD EMORY UNIVERSITY ACADEMY MUSEUM.

## HAWAII

- HONOLULU BERNICE P. BISHOP MUSEUM, Hawaiian Hall.  
 A collection of minerals and rocks of Hawaii and other Pacific Islands, numbering 1100 specimens. Open weekdays 10 A.M. to 4 P.M., and Sundays 2 P.M. to 5 P.M.  
 UNIVERSITY OF HAWAII. Department of Geology.  
 KILAUEA HAWAIIAN VOLCANO OBSERVATORY, Kilauea National Park Museum.

## IDAHO

- MOSCOW UNIVERSITY OF IDAHO, Department of Geology.  
 A general collection, for teaching purposes, in custody of Dr. F. B. Laney. It may be seen daily from 8 A.M. to 5 P.M. except Saturdays and Sundays. Unusual specimens of cerussite, covellite, and zeolites (from Challis, Idaho) are in the collection.

## ILLINOIS

ABINGTON	HEDDING COLLEGE.
BLOOMINGTON	ILLINOIS WESLEYAN UNIVERSITY POWELL MUSEUM.
CARLINVILLE	BLACKBURN COLLEGE.
CARTHAGE	CARTHAGE COLLEGE.
CHICAGO	CHICAGO ACADEMY OF SCIENCES. FIELD MUSEUM OF NATURAL HISTORY. Oliver C. Farrington, Curator.

The principal exhibits include the H. N. Higinbotham collection of gems and gem minerals, the Chas. M. Higginson Collection (3240 specimens, 400 species) presented by Mrs. Higginson in 1928, rich in New England minerals, the William F. Chalmers crystal collection, and the Ward-Coonley collection of meteorites.

UNIVERSITY OF CHICAGO WALKER MUSEUM. Dr. E. S. Bastin, Custodian.

The collections, now numbering 3000 specimens, and exhibited in Rosenwald Hall, contain the Henry A. Ward Collection of the Chicago World's Fair of 1893 and the cabinet of W. C. E. Seeboeck. Many fine calcites are included. The collection is open to visitors on weekdays.

DECATUR	THE JAMES MILLIKAN UNIVERSITY.
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Two cases of 500 minerals and rocks are exhibited on the second floor of Liberal Arts Hall.

ELGIN	ELGIN SCIENTIFIC SOCIETY.
EVANSTON	NORTHWESTERN UNIVERSITY.
GALESBURG	E. MITCHELL GUNNELL, 595 East Losey Street. A general collection of 1500 attractive specimens.
	KNOX COLLEGE.
HANOVER	T. D. SHIPTON. A general collection of 2000 specimens.
LAKE FOREST	LAKE FOREST COLLEGE MUSEUM.
LINCOLN	LINCOLN COLLEGE (of JAMES MILLIKAN UNIVERSITY).
NAPERVILLE	NORTHWESTERN COLLEGE.
PEORIA	WILLIAM C. MCKINLEY.
ROCK ISLAND	AUGUSTANA COLLEGE.



SPRINGFIELD STATE MUSEUM. Centennial Building. A. S. Coggeshall, Curator.

A general collection of 20,000 specimens. Open weekdays 8:30 to 5; Saturdays 8:30 to 3; Sundays 2 to 5 P.M.

STERLING WHITESIDE COUNTY HISTORICAL SOCIETY.

URBANA UNIVERSITY OF ILLINOIS. Museum of Natural History.

A general collection of 3000 specimens.

WHEATON WHEATON COLLEGE.

#### INDIANA

BLOOMINGTON INDIANA UNIVERSITY MUSEUM.

BRAZIL R. T. PHILLIPS, 439 Leavitt Street.

BROOKVILLE BROOKVILLE SOCIETY OF NATURAL HISTORY.

CRAWFORDSVILLE WABASH COLLEGE, HOVEY MUSEUM.

FRANKLIN FRANKLIN COLLEGE OF INDIANA.

Mr. Charles A. Deppe is custodian of a collection of minerals in the main building.

HANOVER HANOVER COLLEGE.

INDIANAPOLIS BUTLER COLLEGE

CHILDREN'S MUSEUM, 1150 North Meridian Street.

Two thousand specimens are exhibited in this children's museum. Open daily, and on Sunday's from 2 to 5 P.M. Mr. Arthur B. Carr is director.

JOHN EALY, North Jefferson Avenue.

INDIANA STATE MUSEUM, State House basement.

Mr. Verne Patty is Custodian of the state collections, which may be seen daily, except holidays.

LAFAYETTE PURDUE UNIVERSITY.

NEWCASTLE HENRY COUNTY HISTORICAL SOCIETY MUSEUM.

NEW HARMONY WORKINGMEN'S INSTITUTE.

Some minerals and rocks of Maclure, Say, Lesueur, and Owen may be seen in the Library daily from 8 A.M. to 8 P.M. and on Sundays from 3 P.M. to 8 P.M.

NOTRE DAME NOTRE DAME UNIVERSITY.

RICHMOND EARLHAM COLLEGE.

TERRE HAUTE ROSE POLYTECHNIC INSTITUTE.

The Second Collection of George Frederick Kunz (1879).

UPLAND TAYLOR UNIVERSITY, WALKER MUSEUM.

## IOWA

## CEDAR FALLS IOWA STATE TEACHERS COLLEGE.

A general collection of several thousand specimens is in the library building;  
Mr. E. J. Cable is Custodian.

## CEDAR RAPIDS COE COLLEGE.

About 1000 specimens are contained in Science Hall, Mr. S. W. Stookey,  
Custodian.

## COLLEGE SPRINGS AMITY COLLEGE.

## DAVENPORT DAVENPORT ACADEMY OF SCIENCE.

## DES MOINES RAYMOND SEEBURGER.

## DUBUQUE HERMANN MUSEUM OF NATURAL HISTORY.

## FAYETTE UPPER IOWA UNIVERSITY.

## GRINNELL GRINNELL COLLEGE; PARKER MUSEUM OF NATURAL HISTORY, Mr. H. W. Norris, Custodian.

A small general collection of about 200 specimens may be seen daily except  
Sunday.

## INDEPENDENCE PUBLIC LIBRARY.

## IOWA CITY STATE UNIVERSITY OF IOWA.

A small collection of 200 specimens.

## MOUNT VERNON CORNELL COLLEGE.

## MUSCATINE MUSCATINE ACADEMY OF SCIENCE. Earlier collections were destroyed by fire.

## SIOUX CITY SIOUX CITY ACADEMY OF SCIENCES AND LETTERS.

## TOLEDO WESTERN COLLEGE.

## WATERLOO CLYDE D. ALLAN, 1221 West Fourth Street.

A general collection of 500 specimens, emphasizing "mineral freaks."

H. W. GROUT, 603 First National Bank Building.

Collection is at present in the Court House, and will be placed later in the  
new Y.M.C.A. building.

## WAVERLY WILLIAM COOK, 500 W. Bremer Avenue.

## WARTBURG NORMAL COLLEGE

A general collection Aug. Englebracht, Custodian.

May be seen Thursday afternoons.

*(To be continued)*